BULLETIN NO. 21

Lead and Zinc Deposits

OF

Northwestern Illinois

BY

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LETTER OF TRANSMITTAL

Governor E. F. Dunne, Chairman, and Members of the Geological Commission:

GENTLEMEN: I submit herewith a report on the Lead and Zinc Deposits of Northwestern Illinois, and recommend that it be published as Bulletin No. 21.

The author, Mr. G. H. Cox, is professor of geology at the Missouri School of Mines. He has made investigations in our lead and zinc district during several field seasons and as a result presents this complete illustrated report.

Lead has been mined in this region ever since early explorations in 1700. It reached its maximum at the time of the Mexican war, since which time the output of zinc has been more important.

The report presents the history of the industry, the general geology of the region, the origin of the ores, and practical notes on prospecting, mining, and milling. The maps will be found to be highly valuable as an aid to locating new deposits and extending present developments.

Very respectfully,

FRANK W. DeWOLF, *Director*

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HISTORY OF MINING

The presence of lead ore in the upper Mississippi Valley was reported by the French explorers as far back as 1658. Some time later than this as the traders gradually pushed up the Mississippi River, lead became an article of barter between the traders and the Indians. Gradually the district became better known so that by 1687 it was shown on Hennepin's map. In 1886 Whitney[1] wrote as follows:

The Galena limestone is by far the most interesting and important mineral-bearing deposit in the State, being the principal depository of the ores of lead and zinc, the former of which has been successfully mined in the vicinity of Galena ever since the first settlement of the country by the French. These mines are said to have been discovered by M. Le Seuer, who made an exploring trip up the Mississippi in the year 1700, but no attempt was made to work the mines until a century later when Julien DuBuque, a half-breed of French and Indian descent, obtained a grant of land from the Fox Indians on the west side of the Mississippi, including the present site of the city of Dubuque, and commenced the business of lead mining in 1788, which he prosecuted successfully until his death in 1810. From that time on, the business was gradually extended, and in 1823 the tide of emigration began to flow rapidly from Kentucky and some of the eastern states, toward this Eldorado of the northwest, and in the next succeeding decade, "diggings" had extended over nearly the whole extent of the lead bearing rocks of this region, including also that part of the mineral region embraced in the present area of the States of Illinois and Wisconsin.

The discovery of the ores has also been attributed to Perrot in 1692, but Le Seuer is usually given the priority. Whether the first ore was mined in Iowa, Wisconsin, or Illinois is not definitely known, but it was probably in Iowa. Although DuBuque confined his mining to the west side of the river, he apparently purchased from the Indians ore which they had mined on the east side of the river.

After the death of DuBuque in 1810, the red man again claimed the territory and became hostile to the whites, so that for a time all mining was confined to the east side of the river, a condition which hastened the development of this portion of the area. In 1815[2] about twenty furnaces are said to have been operated by the Indians near the present site of Galena, but the first mining by white men at this point was probably in 1821 or 1822, and, up to 1824, was confined to prospects formerly worked by the Indians. In 1807 the Government reserved 345,600 acres in northwestern Illinois to be leased on an annual rental, the royalty being one-sixth to one-tenth payable in cash or lead. However, the cost of collection was so high (about forty-six cents on a dollar) that the plan was abandoned in 1846. The total number of leases granted was 2,093, the first having been obtained by Col. James Johnson, who in 1823 began operations on a considerable scale near Galena.

[1] Whitney, J. D., Geological Survey of Illinois, Vol. I, p. 141, 1866.
[2] Bain, H. F., U. S. Geol. Survey Bull. 294, p. 3, 1906.

A. Hughlett furnace in operation about 1890.

B. Hughlett furnace as it appears today.
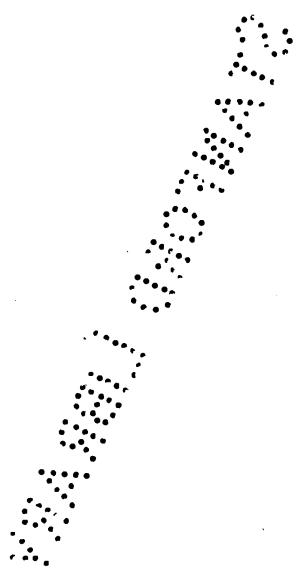
The village of Galena was laid off in 1827, and *permits* were granted to individuals to occupy and improve lots on condition that they were to be surrendered to the United States Agent upon thirty days notice. These *permits* were the only titles the citizens had to their lots or improvements up to 1838, when the town was re-surveyed under an act of Congress, and the settlers allowed a pre-emption right to their lots and improvements.[3]

By 1836 the mining operations had become general so that Galena was a thriving typical western mining town. It became the objective point of all railroads running west from Chicago and up the Mississippi River. Practically all the shipments of ore and supplies for the district passed through the city. The larger river packets from New Orleans and St. Louis entered the Galena River and tied up at the wharfs of Galena, where it was no uncommon sight to see fifteen or twenty river boats loaded with either supplies or ore, and the wharfs piled high with pig lead awaiting shipment.

In 1833 mining operations began near the former town of Weston (SW. ¼ sec. 22, T. 27 N., R. 2 E.) near Elizabeth. By 1846, according to James Shaw,[4] Elizabeth is said to have had "1000 inhabitants and 30 saloons." Georgetown (W. ½ NW. ¼ sec. 24, T. 27 N., R. 2 E.) was also an active mining town at this time, but at the present writing not one building is left to mark its former site, and but two buildings are left to mark that of Weston. Mining has also been carried on intermittently at numerous other points within that area of northwestern Illinois which is limited on the east, southeast, and south, by the towns of Scales Mound, Stockton, Morsville, Elizabeth, Hanover, Mt. Carroll, and Savanna.

About 1854, Galena still being the chief city of the lead region and one from which all of the ore from Illinois and a large portion of that from Wisconsin was shipped, successful attempts were made by private capital to better the transportation facilities by the construction of a wagon road from Galena to Hazel Green, Wis., with the expectation that the toll received would be sufficient to pay cost with interest. The road was first graded after the manner used for railroads and planked as far as the State line, but the oak planks curled so badly by exposure to the weather that they were soon replaced by macadam. Toll was collected on this road until about eleven years ago. The road is still known as the "Turnpike" and is one of the best roads in this part of the State.

The next important event in the history of the district was the erection of a plant at LaSalle in 1852 for the reduction of the zinc ores. Previous to this time the zinc ores had no commercial value, and when encountered in mining for lead were thrown away. After this the production of zinc rapidly increased and that of lead, the maximum produc-

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[3] Whitney, J. D., Geological Survey of Illinois, Vol. I, p. 141, 1866.
[4] Shaw, James, Geology of JoDaviess County: Geological Survey of Illinois, vol. V, p. 45, 1873.

tion of which was reached in 1846-8, gradually decreased, so that the total tonnage of zinc ore produced up to 1909 for the whole upper Mississippi Valley district exceeded that of the lead ore. The production for the year 1908, was about 59,000 tons of zinc ore to about 4,000 tons of lead ore. The area is now zinc rather than lead producing, a relation which it is believed will last as long as the district.

HISTORY OF SMELTING

As the production of lead increased furnaces were erected at suitable locations over the area. In 1815 there are said to have been twenty furnaces in operation by the Indians near the present site of Galena. In 1846-8 it is reported that there were at least twenty-four smelting furnaces in active operation in JoDaviess County. In 1866, there were five furnaces running in Illinois producing about 8,750,000 lbs. of lead per year. In 1878 there were still five furnaces in JoDaviess County, but they were not being run at their full capacity. These were the Hughlett furnace at Galena (Pl. I) (the largest), the Spencely furnace at Vinegar Hill, the Bowden furnace (Pl. II), southwest of Council Hill, the Green furnace at Elizabeth, and the Stevens furnace at Rice. · There was also a small furnace near Warren. The log furnaces used by the Indians and the early whites were crude affairs but fairly efficient. They were always built on steeply sloping ground, the first ones consisting of two logs laid parallel to the hillside, the lower log being the larger. Across these were piled wood and ore, while a pit, dug in the earth just below the furnace, served to catch the molten lead as it ran down the slope. Later these furnaces were constructed in pairs, each being about four feet wide, by building stone walls on three sides and through the center, the sloping ground constituting the fourth side and bottom. The wall lowest on the hillside was eight feet high, while the ends and the center wall varied from this to nothing as they ran up the slope. The bottoms of the furnaces were paved with flat stones, although irregular ones were placed at the ends, in order to prevent the wood from lying flat on the bottom and interfering with the flow of the lead. Holes were made at the base of the lower wall which answered the double purpose of permitting a draft for the furnace and an outlet for the molten metal which was caught in a pit in the ground. From this it was dipped and poured into molds, forming "pigs" of 75 to 80 pounds each.

The charge consisted of a layer of four-foot logs on the bottom, a layer of smaller wood standing vertically on three sides, with about 2,500 pounds of ore in the center, the larger chunks being placed at the bottom. Upon this, wood was continually added until the logs burned out below,

Bowden furnace near Galena, Ill.
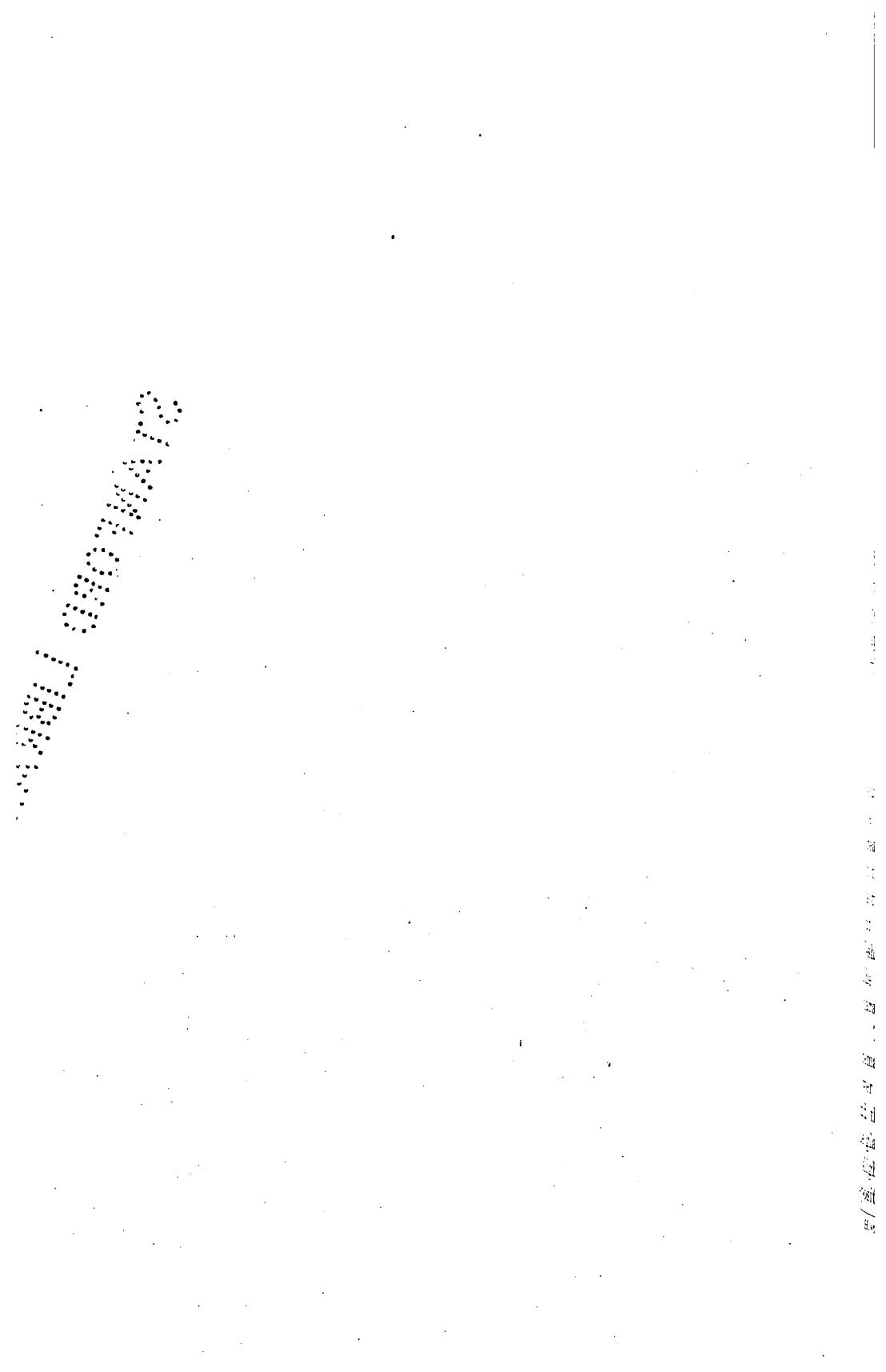
when the fire was allowed to die out. This "run" required from 16 to 24 hours. Each smelter usually had two or more of these furnaces so that one might be used while the other was being cleaned out. The furnaces made two products, pig lead and "ash" (ashes containing much lead). The latter was resmelted in an "ash furnace."

The introduction of the "blast" and "cupola" furnaces, invented in 1837, put an end to the use of log furnaces.

The "cupola" or chimney of the furnace of that name was from thirty to forty feet high, with a flue of about eighteen inches in diameter, and was so constructed as to cause the blaze and heat from the fire to pass over the mineral, and it was necessary to keep it in operation constantly, day and night. The "blast furnace" was so called because a strong and constant current of air was sent into the fire from a bellows, driven by water or other power. The furnace "blows out" in from six to twelve hours. The blast furnace requires more labor and less fuel than the "cupola." Ordinary furnaces smelted from sixty to one hundred and fifty pigs of lead, of seventy pounds each, per day. At some of them two hundred pigs per day were manufactured in the palmy days of the mining interest.[5]

So far the smelting operations had been confined to the use of lead ores, but the discovery of a process for the reduction of zinc from its ores by Mathiessen and Hegeler resulted in the erection of a plant for the treatment of the zinc ores at LaSalle in 1852. In 1859 a zinc oxide plant was erected at Mineral Point, Wis., to which were later added appliances for the manufacture of sulphuric acid from the sulphur fumes which had previously been lost.

TOPOGRAPHY

GENERAL STATEMENT

The lead and zinc district of northwestern Illinois lies at the southern end of the so-called Driftless Area. All parts of the district lie within thirty miles of the Mississippi and wholly within the rough area immediately adjacent to this stream. The steep, precipitous sides of the channel of the Mississippi and the less steeply inclined banks of its two chief tributaries within the district, Apple and Galena rivers, are cut by numerous small streams and ravines which occupy rather V-shaped valleys, conditions which are typical of young topography. The larger the valleys become, the more they exhibit a flat-bottomed character similar to that of valleys in maturity.

The area, however, bears the appearance of a district of mature age prematurely old, because of the overloading of its major streams in their lower courses upon the partial retreat of the glaciers from the district, and the partial filling of its valleys with wash material. Later, when the glaciers had entirely withdrawn from the region, there was apparently a slight rejuvenation of the streams, and they began to cut into the deposits they had previously laid down. So far, the streams have low-

5 History of JoDaviess County, p. 841, 1878.

ered their beds about thirty feet, but have not reached bed rock nor are they liable to do so soon, for the bed rock of the tributary streams near their mouths is lower than the present bed of the Mississippi.

UPLANDS AND MOUNDS

The larger portion of the zinc and lead area has been regarded by Grant and Burchard as a somewhat dissected, Tertiary peneplain, cut by numerous valleys, for the uplands are flat and rise to the same general level. The evidence of this[6] peneplain is best seen from some high point of vantage, as on the hills upon which the higher portions of Galena are situated. (See Pl. III.) The generally even sky line, broken only here and there by slight projections, and the continuation of this plane over southern Wisconsin where it bevels geologic formations of various ages, are regarded as sufficient evidence to establish the probability of the existence of the "Lancaster" peneplain at this elevation.

Rising about 200 feet above this general plain, which averages between 200 to 300 feet above the level of the Mississippi River, or about 800 or 900 feet above sea level, are scattered elevations known as mounds and ridges. These are apparently monadnocks or old erosion remnants on the peneplain. They are composed largely of Maquoketa shale (Pl. IV, *A*), but owe their permanence to a hard, resistant cap of Niagara dolomite. As the mounds and ridges are approached, the country rises with a gradually increasing slope until the Niagara dolomite is reached, where the ascent becomes abrupt, so that it is often possible to estimate the position of the Maquoketa-Niagara contact quite closely by the change in the topography. (See Pl. IV, *B*.) In horizontal section the mounds may have various shapes, as indicated by the name of Horseshoe Mound, but they are usually round or oval.

The ridges are usually flat topped and are divided into branching, finger-like portions. This flat top of the ridges, standing at about the same altitude as the tops of the mounds, is thought by some to be a remnant of a pre-Tertiary peneplain. The heights above sea level of some of the mounds as determined by topographic surveys are as follows: Charles Mound 1,241, Scales Mound 1,145, Horseshoe Mound 1,070, Dygert's Mound 1,015, and Pilot Knob 1,007 feet. At places along the Mississippi and its tributary streams the change from the uplands to the valleys between them is precipitous, but elsewhere the descent may be steep or gradual.

VALLEYS

The bottom lands of the Mississippi and its tributaries, Apple, Galena, Sinsinawa, and Menominee rivers, and Smallpox Creek, comprise

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[6] Grant, U. S., and Burchard, E. F., U. S. Geol. Survey Geol. Atlas, Lancaster and Mineral Point folio (No. 145), p. 2, 1907.

View showing city of Galena, terraces, peneplanation, and mounds.

the valleys. The banks of the Mississippi are invariably steep and in many cases precipitous, rising abruptly to a height of 100 to 200 feet and in many places reaching an elevation of over 300 feet above the river level within a distance of half or three-quarters of a mile inland. These valleys are characterized by slow, meandering streams with broad, low-lying flood-plains on either side (Pl. V, A). The surface of the Mississippi River, although varying with the season, is usually between 590 and 600 feet above sea level, and its valley at this point is about 1½ miles wide. The course of the stream shows a slight response to the structural conditions of the rocks over which it flows, such as the low east-west anticlines, which it crosses. At protected points along the banks of the river and of its tributaries are well-formed terraces, remnants of river beds occupied during the glacial period. Where uneroded, the terraces in this district have an elevation of 635 to 655 feet above sea level and slope towards the center of the stream; along the streams the tops of the terraces are nearly horizontal (Pl. V, B).

Most of the valleys are rather broad for the present size of their streams. They are flat bottomed, as is usually the case where flood-plains have been well developed, and contain a large amount of alluvial material so that, when above the level of the flood waters, they constitute excellent farm lands. The depth of the alluvium has been shown[7] to vary from 100 to 150 feet at points in the valley of the Mississippi. Along the tributary streams it decreases from this amount at their mouths and is absent at their upper ends. A depth of at least sixty feet has been reported along the Galena River at Galena.

[7] Grant, U. S., and Burchard, E. F., U. S. Geol. Survey Geol. Atlas, Lancaster and Mineral Point folio (No. 145), p. 2, 1907.

CHAPTER II—GEOLOGY

STRATIGRAPHY

GENERAL STATEMENT

The geology of the district is simple, and all the rocks exposed at the surface or reached by the deepest wells are of sedimentary origin, except the loess, which is wind blown. The lithologic changes in the vertical section (fig. 1) indicate that the conditions under which sedimentation took place varied. Sandstone, limestone, and shale were formed in Paleozoic seas, which at times receded from the land and again encroached upon it. At times the sea became so shallow that sand was deposited, at other times the former sea bottom actually protruded above water in places so that it suffered slight erosion.

As the formations were studied they were divided into various groups and were given distinctive names by the geologists who studied them. The names employed by those who have done most work in the district are given in the following tables:

Table of names used by different authors to designate the formations in the lead and zinc district of Illinois

Owen, 1852	Hall, 1858	Worthen and Meek, 1866	Irving, 1876	McGee, 1891	Calvin, 1897	Bain and Grant, 1906	
Upper Magnesian	Niagara	Niagara	Niagara	Niagara	Niagara	Niagara	
	Hudson-river	Cincinnati*	Cincinnati	Maquoketa	Maquoketa	Maquoketa	
	Galena	Galena	Galena	Galena	Galena	Galena	
St. Peter's Shell Limestone	Trenton	Trenton	Trenton	Trenton	Trenton	Platteville	
St. Peter's	St. Peter's	St. Peter's	St. Peter's	St. Peter	St. Peter	St. Peter	
Lower Magnesian	Calciferous or Lower Magnesian	Lower Magnesian or Calciferous	Lower Magnesian	Oneota	Oneota	Prairie du Chien	Shakopee, New Richmond, Oneota
Lower Sandstone	Potsdam	Potsdam	Potsdam	Lower or Potsdam	Potsdam	Potsdam	

* Named by White, Geology of Iowa, vol. I, p. 181, 1871.

The vertical distribution of the formations in the district are indicated in figure 1.

Formation Name	SCALE OF FEET	Columnar Section	THICKNESS IN FEET
Niagara dolomite	1875 1750		0-140
Maquoketa shale	1625		120-200
Galena dolomite	1500 1375		240
Platteville limestone			55
St. Peter sandstone	1250		35-170
Prairie du Chien	1125 1000		150-250
Cambrian sandstone	875 750 625 500 375 250 125		1000

Exposed at surface in the region

Not exposed at surface in the region
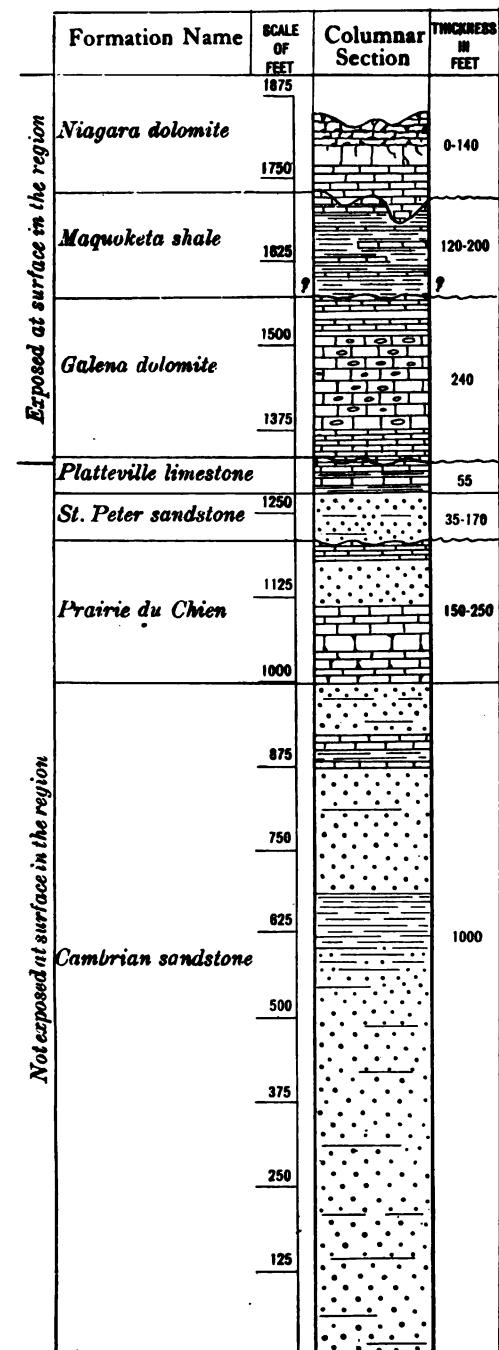
FIG. 1. Columnar section through the rocks of the lead and zinc region in northwestern Illinois.

No rocks younger than the Niagara dolomite have been found in the district. If they ever existed all trace of them has been removed. Only remnants of the Niagara dolomite and the Maquoketa shale have thus far withstood the attack of erosion and are to be seen as isolated mounds and ridges composed of shale, with or without a cap of resistant dolomite. For the greater part of the district the Galena dolomite directly underlies the soil.

In a few places in the upland it is covered by isolated patches of Maquoketa shale. In some of the valleys at the northern end of the district, near the Wisconsin line, the Platteville limestone is at the surface, but no rock older than this is exposed anywhere in the area.

PRE-CAMBRIAN ROCKS

Pre-Cambrian igneous and metamorphic rocks underlie the whole area at a depth of about 1,500 feet below the base of the Galena dolomite. Their nature can be inferred only from drill records and exposures in neighboring regions. Their nearest ex-

posure is near Baraboo, Wis., where the Baraboo quartzite, classified by Weidman as middle Huronian, averages about 4,500 feet thick and lies upon much older rhyolites, granites, diorites, and other types. The pre-Cambrian rocks form an irregular erosion surface which has a general southern dip similar to that exhibited by the Paleozoic strata.

<div align="center">POTSDAM SANDSTONE</div>

This sandstone includes the upper and a part of the middle Cambrian series. It is not exposed within Illinois, but is well exposed along the Wisconsin River at the north edge of the lead and zinc district of Wisconsin. Here, it is composed largely of sandstone with some shale and dolomite. Because of the depth to which the formation is buried, and the lack of information concerning it, no sub-division is attempted. Its only importance in this district is as a possible source of water. Study of available drill records shows that the top of the formation tends to become shaly towards the south, so that in the southern portions of Wisconsin it is necessary to penetrate it to a distance of several hundred feet to obtain a flow of water. It apparently thickens to the south, as drill holes have penetrated it 1,000 feet without finding its base.

<div align="center">PRAIRIE DU CHIEN SERIES OR LOWER MAGNESIAN DOLOMITE</div>

<div align="center">ORIGIN OF NAME</div>

The name Lower Magnesian was applied to this series of rocks by Owen[1] in 1840, in contrast to Upper Magnesian, a series under which were included all the beds between the base of the Galena dolomite and the top of the Niagara dolomite, on the assumption that these constituted a continuous dolomitic series. The discovery of the shale beds between the Galena and the Niagara formations caused the Upper Magnesian to be later subdivided into three separate formations. Irving[2] in 1875, mistaking the sandy central portion of the Lower Magnesian formation for the St. Peter sandstone, gave the name Oneota to its lower and main portion consisting of about 200 feet of massive dolomite, which he thought to be the Lower Magnesian of Owen. He was later followed in this grouping by McGee[3] who also placed the overlying beds with what is now known as the St. Peter sandstone. Calvin[4] used the Oneota as the equivalent of the Lower Magnesian of Owen and Lower Oneota for the basal dolomitic member. Disliking to use the term

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[1] Owen, D. D., Ex. Doc. 239, 26th Cong., 1st sess., p. 17, 1840.
[2] Irving, R. D., Am. Jour. Sci., 3d ser., vol. 9, p. 442, 1875.
[3] McGee, W. J., U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, p. 332, 1891.
[4] Calvin, Samuel, Iowa Geol. Survey, vol. 6, pp. 115–428, 1896.

A. Flat character of bottom lands and meandering course of Apple River.

B. Remnants of glacial terraces.

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ower in a titular sense, Bain[5] and Grant[6] used the Oneota of Irving ɾith the New Richmond and the Shakopee of the Minnesota Survey, pplying the name Prairie du Chien to the series as a whole.

ONEOTA DOLOMITE

The Oneota dolomite is the basal member of the Prairie du Chien eries and consists of about 200 feet of massive dolomite.

NEW RICHMOND SANDSTONE

The New Richmond sandstone is a light-colored, poorly cemented andstone varying in thickness from 15 to 150 feet. It is rather widely listributed, and extends as far west as Des Moines,[7] Iowa. This forma-ion somewhat resembles the St. Peter sandstone for which in some cases t has been mistaken. In general, however, it is not as uniform in text-.re or composition, or as thick bedded as is the St. Peter, and it contains mpurities such as clay, chert, and iron oxide, which are rarely, if ever, een in the St. Peter.

SHAKOPEE DOLOMITE

The Shakopee dolomite constitutes the upper portion of the Prairie ιu Chien or Lower Magnesian series and is 40 to 50 feet thick. It is .owhere exposed within the lead and zinc field in Illinois. In places in he lead and zinc district in Wisconsin, the formation is reported[8] to be hin or entirely absent, apparently in consequence of the erosion that ccurred just before the deposition of the St. Peter sandstone.

The formation as a whole contains, especially in the more dolomitic ayers, much chert and many small cavities lined with drusy quartz rystals, and, where exposed in Wisconsin, the top is usually marked by . band of silicious and calcareous oolite.

In Iowa and Wisconsin a few fossils, consisting largely of gastropods .nd cephalopods, have been found in the series, mainly in the Shakopee lolomites.

ST. PETER SANDSTONE

The St. Peter sandstone is of economic importance as a source f water, of sand for building purposes, and for glass-making. In ;eneral it is a clean, white, poorly cemented sandstone, composed of ɾell-rounded and uniformly-sized grains. In places the sandstone con-ists of over 99 per cent silica (SiO_2). This formation does not outcrop

[5] Bain, H. F., U. S. Geol. Survey Bull. 294, p. 17, 1906.
[6] Grant, U. S., Wis. Geol. & Nat. Hist. Survey, Bull. No. XIV, p. 25, 1906.
[7] Newton, W. H., Iowa Geol. Survey, vol. 6, pp. 115–428, 1896.
[8] Bain, H. F., U. S. Geol. Survey Bull. 294, p. 18, 1906.

in the northwestern Illinois lead and zinc district, but where exposed in Wisconsin and Iowa and farther south in Illinois, it is usually but slightly cemented so that it can often be excavated with a shovel. Where exposed to the weather, as along creeks, however, the sand grains are cemented by iron oxides, causing the rock to assume the character of a hard, reddish, quartzite, which so resists weathering that it stands out in bold scarps along the streams.

In thickness the formation varies both greatly and abruptly, due, in a large part at least, to the erosion of the underlying Prairie du Chien dolomite. In Wisconsin the formation varies from 30 to 175 feet in thickness, and averages about 75 feet. Two records of drill holes at Galena, one of Taylor's flowing well and a doubtful one of the old Galena Electric Plant well, give the St. Peter a thickness of 108 and 129 feet respectively. At Utica, Ill., it has a thickness of 150 feet, and it is reported by Weller[9] as having a maximum known thickness of 275 feet in the State.

PLATTEVILLE LIMESTONE

GENERAL DESCRIPTION

This formation was for years known as the *Trenton* limestone, but because of the rather loose usage of this term and doubt as to its being the exact equivalent of the Trenton in its type locality in New York both Bain[10] and Grant[11] have given it the name Platteville because of its typical exposures near this town in Wisconsin. It directly overlies the St. Peter sandstone and is the oldest formation exposed in the lead and zinc district of Illinois. Its best exposures occur along the Galena River near the southern edge of Council Hill Township, and the glass-rock and upper beds are well shown at the old Tuttle mill in sec. 34, T. 29 N., R. 1 E. Along the southern edge of the Wisconsin field, it varies from 40 to 65 feet in thickness, and averages about 55 feet. A drill hole on the farm of August Geselbracht, SE. ¼ SE. ¼ sec. 24, T. 28 N., R. 1 W., showed 70 feet between the first trace of oil-rock and the St. Peter sandstone, making the Platteville about 60 feet thick at that point.

In general the Platteville limestone is a light-bluish rock when fresh, and weathers to a light buff. Where unweathered the beds may appear massive, but on exposure they often break up into thin shaly layers which may be separated by clay partings. The lower beds are more massive and are known as the "lower buff" or "quarry" beds, (Pl. VI) which

[9] Weller, Stuart, Ill. State Geol. Survey, Bull. 6, p. 15, 1907.
[10] Bain, H. F., U. S. Geol. Survey Bull. 246, p. 17, 1905.
[11] Grant, U. S., Wis. Geol. and Nat. Hist. Survey, Bull. XIV, p. 23, 1906.

Jointing in Platteville limestone.   (Courtesy of Wisconsin Geological and Natural History Survey.)
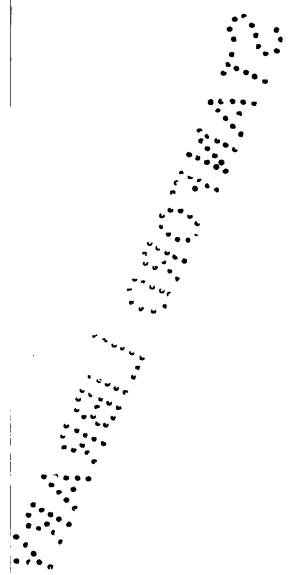
are extensively used for building purposes in Wisconsin. A general section of the Platteville limestone, according to Grant,[12] is as follows:

General section of the Platteville limestone

		Feet
4.	Thin beds of limestone and shale	10-20
3.	Thin-bedded, brittle, fine-grained limestone	15-25
2.	Thick-bedded, magnesian limestone or dolomite	15-25
1.	Blue shale, sometimes sandy	1-5

No. 1 marks the division between the St. Peter sandstone below and the Platteville limestone above. In general, this clay bed seems to thicken towards the west. It is absent at Mt. Horeb, Wis., and Rockton, Ill., but is reported[13] by Hall and Whitney as being 1 to 3 feet thick in eastern Iowa. It varies from 1 to 5 feet in thickness at Lancaster, Wis., and thins out to the north.

No. 2 is a somewhat porous, dolomitic limestone. It can usually be distinguished from the other Platteville strata above by its thick, massive bedding, and from the Galena dolomite by its smaller porosity, lack of cherts, and less irregularly weathered surface. These are the so-called "lower buff" or "quarry" beds and vary from 8 inches to 3 feet in thickness.

No. 3 usually occurs in thin, wavy, shale-like layers about 2 inches thick, often separated by thin clay partings. It may at times be massive, especially where not weathered. In places these beds approach the glass-rock beds of No. 4 in character and composition, although more thinly bedded.

No. 4 consists essentially of thin, shaly limestone and thin seams of shale, both of which are very fossiliferous. This includes the main glass-rock beds and the so-called "glass-rock opening," the latter name being applied to the strata 2 to 3 feet thick that lie directly below the main glass-rock beds. The ore sometimes occurs in this "opening" which then consists of either a clay bed or a much fractured, thin-bedded limestone. Towards the west there is a tendency for the thin, shaly beds to be replaced by clay. At Mineral Point, Wis., there are about 2 feet of clay below the glass-rock; at Cassville, Wis., 2+ feet; at Potosi, Wis., 6 feet; at Dubuque, Ia., 1+ foot; and at Rockton, Ill., none. These thin beds usually differ from those of the main glass-rock, described below, by being thin, wavy, and interstratified with clay and, to some extent, with oil-rock. The characteristic fossils are, according to Grant: *Maclurea bigsbyi, Zygospira* (Hallina) *nicolleti, Hindia inaequalis, Rhinidictya, Phylloporina sublaxa, Monotrypa magma, Rhynchotrema*

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[12] Wis. Geol. and Nat. Hist. Survey, Bull. XIV, p. 31, 1906.
[13] Geology of Iowa, vol. I, pt. 1, p. 57, 1858.

minnesotensis, Ambonychia planistriata, Chonychia lamellosa, Salping-ostoma buelli, Conradella triangularis, Hyolithes baconi, Ecrinurus vannulus, and sponges of the genera *Anthaspidella* and *Zittelella.*

<div align="center">GLASS-ROCK</div>

From 3 to 10 feet below the top of No. 4, as given above, occurs a stratum of a hard, compact, chocolate-colored rock varying from 6 inches to 5 feet in thickness and locally known as the main *glass-rock.* The series consists of layers from 2 to 6 inches thick. Chemically, it is a rather pure limestone, consisting of over 85 per cent calcium carbonate ($CaCO_3$). A maximum thickness of 15 feet is reported by Grant for Wisconsin, but where the bed is thick the rock often loses many of its typical characters. The glass-rock, like the oil-rock (fig. 2) is practically coextensive with the district. In Wisconsin, the glass-rock is absent at Mt. Horeb but abundant at Dodgeville; is thin at Montfort, but thick at Lancaster. In the vicinity of Highland, it varies from 8 inches to 5½ feet, being 5 feet thick at the Kennedy mine. It is poorly developed at Bagley and Glenhaven but prominent at Cassville and Potosi, Wis. It is present at North Buena Vista, Specht's Ferry, and Dubuque, Ia., and at Galena, Ill., but is absent at Rockton, Ill.

In the northern portion of the Wisconsin field, considerable ore has been found associated with the glass-rock, but within Illinois no ore in paying quantities has been found at this horizon.

<div align="center">GALENA DOLOMITE</div>

<div align="center">GENERAL DESCRIPTION</div>

The Galena is the main ore-bearing formation of the district, the ore being found mostly in its lower half. In general, it is a porous (Pl. VII), magnesian limestone approaching dolomite in composition as shown by the following analysis:

<div align="center">*Analysis of the Galena dolomite*[14]</div>

Carbonate of lime ($CaCO_3$).. 54.33
Carbonate of magnesia ($MgCO_3$).................................. 41.56
Sesquioxide of iron (Fe_2O_3)..................................... .90
Alumina (Al_2O_3).. .99
Silica (SiO_2)... 2.10

<div align="right">99.88</div>

[14] U. S. Grant, Wis. Geol. and Nat. Hist. Survey, Bull. XIV, p. 39, 1906.
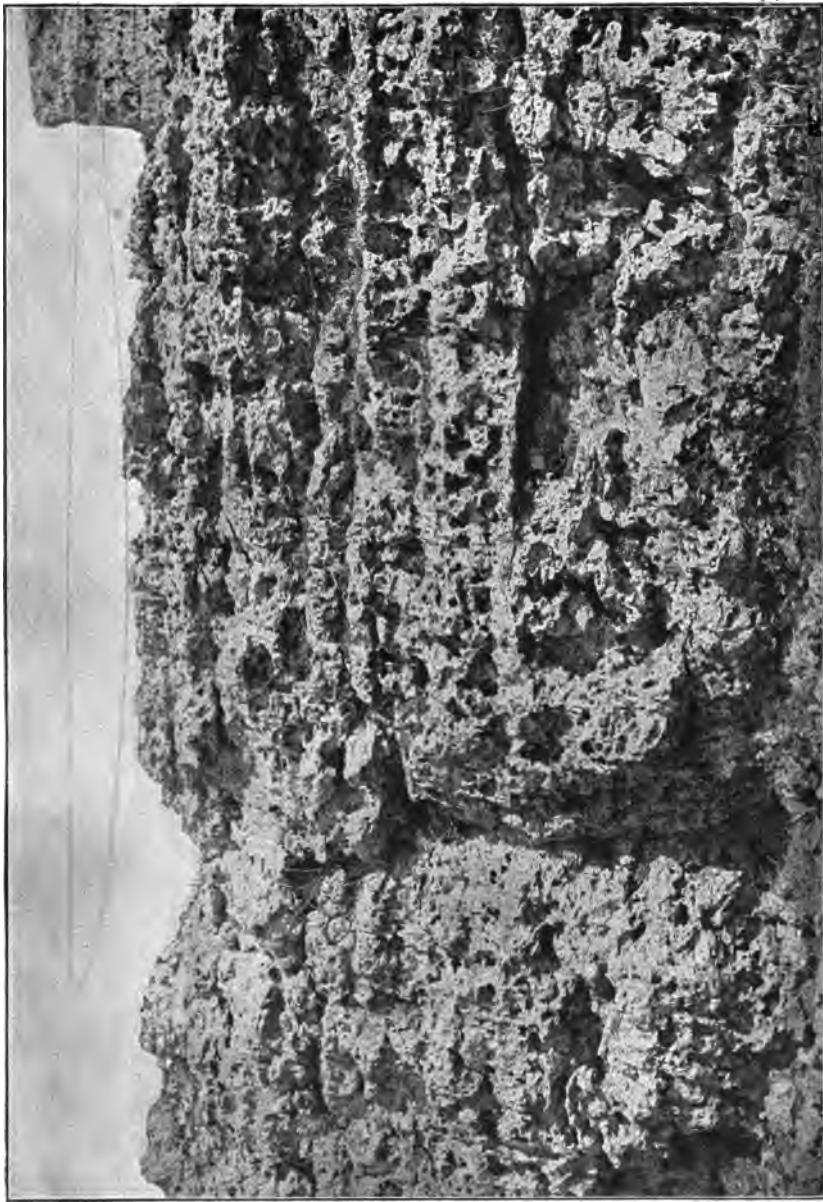
Weathered surface of Galena dolomite.   (From Iowa Geological Survey.)

Analysis of Galena dolomite from Eagle Point, Dubuque, Iowa[15]

	I	II
Water	0.02	0.04
Insoluble	2.15	8.63
Calcium oxide (CaO)	30.72	28.86
Iron sequioxide (Fe$_2$O$_3$)	.82	.85
Phosphorus pentoxide (P$_2$O$_5$)	.60	.57
Magnesium oxide (MgO)	19.90	18.82
Carbon dioxide (CO$_2$)	45.91	42.08
Organic	.13	1.07
	100.25	100.92

A general section from the top down as given by Grant and Burchard[16] is as follows:

General section of Galena dolomite

Feet

5. Dolomite, earthy, thin bedded.................................... 30
4. Dolomite, coarsely crystalline.................................... 60
3. Dolomite, thin to thick bedded, coarsely crystalline, chert bearing... 90
2. Dolomite, thin bedded, coarsely crystalline....................... 50
1. Thin-bedded limestone with shaly partings which are highly fossiliferous and, in part, at least, carbonaceous—the oil-rock of the miners 2-10

No. 1 usually consists of thin layers of limestone with partings of shale and oil-rock. In places they closely resemble the thin glass-rock beds near the top of the Platteville and are distinguished from them with some difficulty in limited exposures. Grant believes that beds of this character are usually found in the oil-rock basins. At the bottom of this division occurs the main oil-rock bed, the base of which is taken as the division between the Galena and Platteville formations. Where present in Wisconsin this bituminous layer varies from a few inches to five feet in thickness, but in Illinois the presence of a main oil-rock bed is not pronounced. This contact is easily located, nevertheless, by a clay bed which occurs just below the seam and which is about one foot thick. In prospecting for ore it is the custom to stop the drill as soon as oil-rock is encountered, so that no great error is made by assuming, in the absence of other data, that the contact between the Platteville and Galena lies about 10 feet below the base of such drill holes.

No. 2 contains beds of varying thicknesses, those of the upper portion being in general thicker and more dolomitic than those below, both of which characters are more apparent on weathered surfaces. As a rule these beds contain but a few scattered nodules of chert, although chert layers may occur anywhere within the division. Of the five divisions, this one carries the most ore, especially zinc ore.

No. 3 is a rather massive, porous dolomite containing much chert which in general distinguishes it from Nos. 2 and 4. Lead and zinc have been found here in more nearly equal amounts. It contains the so-called "flint openings" as well as many of the crevice deposits.

No. 4 is similar to No. 3 except that it contains but a small amount of chert. While zinc ore has been found here, especially in the form of the carbonate, smithsonite, this horizon more commonly contains lead ore, galena.

No. 5 is also dolomitic but the beds are less massive and more earthy than in Nos. 3 and 4 (Pl. VIII, A). This division is to be found only on the highest uplands from which the Maquoketa shale has been recently stripped, or where the Galena is still overlaid by this shale. It has been found to contain only small amounts of ore.

[15] Bain, H. F., U. S. Geol. Survey Bull. 294, p. 27, 1906.
[16] Grant, U. S., and Burchard, E. F., U. S. Geol. Survey Geol. Atlas, Lancaster and Mineral Point folio (No. 145), p. 6, 1907.

Perhaps the most characteristic features of the Galena formation are its dolomitic character, porous structure, and rough, weathered surface at outcrops, and in these respects, differs quite markedly from its associate, the Platteville limestone. Throughout it contains many fossils of which *Receptaculites oweni* has been found to characterize certain horizons. A few of these fossils are found throughout the entire thickness of the dolomite, but they are particularly characteristic of two zones each about 2 feet thick, one of which zones is about 30 feet below the top of No. 4, and the second 35 to 50 feet above the main oil-rock bed, the lower portion of No. 1.

Some of the more common fossils of the Galena dolomite are the brachiopods and pelecypods—*Orthis tricenaria, O. pectinella, O. testudinaria, Plectambonites sericea, Leptaena charlottae,* certain varieties of *Rafinesquina alternata, and Strophomena incurvata.*

OIL-ROCK

At the base of the Galena dolomite, and sometimes as partings between the thin glass-rock beds of the upper portion of the Platteville

FIG. 2. Map showing distribution of the oil-rock. The outer continuous line marks the outer boundary of the area underlain by oil-rock. Where broken, boundary is uncertain. The inner continuous line incloses the area over which the oil-rock averages a foot or more in thickness. (This thickness includes only the *pure* oil-rock and not the interbedded clay and limestone which are often reported as oil-rock.) The line composed of dashes marks the edge of the non-glaciated district, from which the Maquoketa shale, except in a few small places, has been entirely eroded.

limestone and the lower 10 feet of the Galena dolomite, is a dark bituminous shale known as the *oil-rock.* The bottom of the main body
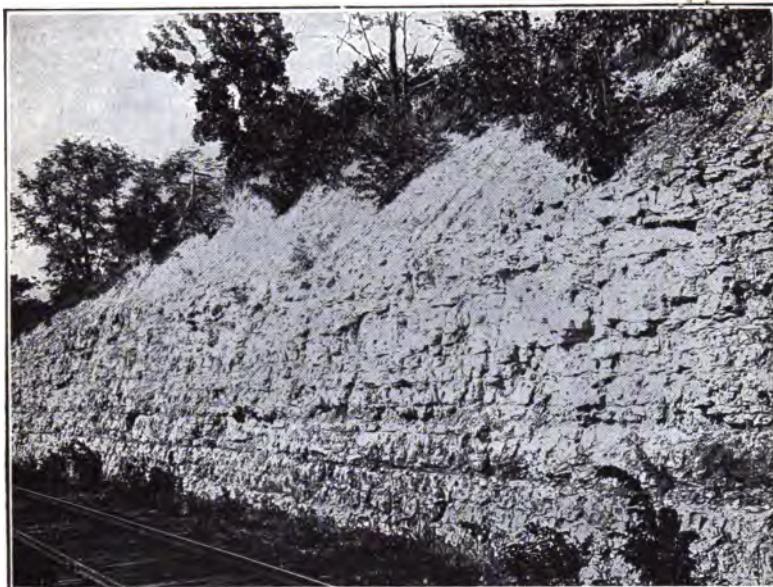
A. Upper thin beds of the Galena dolomite and overlying Maquoketa shale.
(From Iowa Geological Survey.)

B. Exposure showing cherty character of Niagara dolomite.
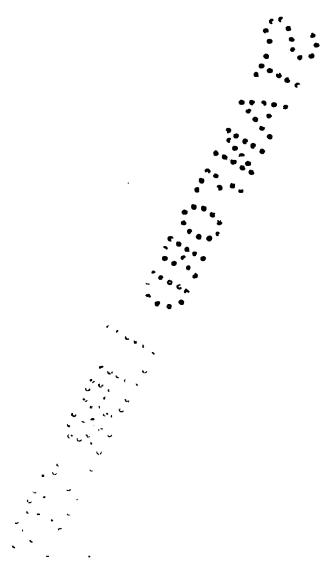
of oil-rock occurring from 3 to 10 feet above the main glass-rock beds is regarded by Chamberlin as the division plane between the Platteville limestone below and the Galena dolomite above, because he recognizes a slight unconformity at this point, and by Ulrich, because this horizon marks the greatest paleontological break in the Galena-Platteville series. Interbedded with the oil-rock, or just below it in many places is a greenish clay bed about a foot in thickness, This is prominent in the western portion of the district, and has been reported by the state geological surveys of Iowa and Minnesota. It is a common thing for miners to report oil-rock as the main oil-rock bed, the clay bed below it, and the thinly bedded glass-rock with oil-rock partings. This accounts for the reports of 10 or 20 feet of oil-rock, when the actual amount of organic shale may be less than a foot.

When wet, the oil-rock is a dark chocolate color, but when dry, is a light gray, and is recognized by its usual laminated structure and by the fact that it will burn. In drilling it is recognized by the color of the cuttings, and by the appearance of oil upon the water. Thin seams of oil-rock are at times found at higher levels in the Galena dolomite, but their presence has no known significance. It is to this thin bed of bituminous shale that many believe the presence of ore in the district is due. Its general distribution and thickness is shown by fig. 2.

Because of the apparent relation between the oil-rock and the ore deposits in some cases, the important part assigned to it by Bain in the origin of the ores, and its possible future importance as a source of gas, the following description of its composition is quoted:

Mr. Rollin Chamberlin courteously undertook the further examination of the volatile constituents of the rock with the following results:

The oil-rock is very porous and light, having a specific gravity of only 1.98 and yielding gas bubbles when placed in water. One volume of the rock gave 57.46 volumes of gas when heated to a red heat in a vacuum for two hours. A gas analysis of this material gave the following results:

Analysis of gas from oil-rock of Dugdale prospect

Hydrocarbon vapors	11.11
Heavy hydrocarbons	4.00
CH_4	35.98
H_2S	6.79
CO_2	18.12
CO	8.40
O	.26
H_2	13.18
N_2	2.21
	100.05

Under the term hydrocarbon vapors are here grouped various hydrocarbons which are liquid at ordinary temperature and which are soluble in alcohol. Benzine may be taken as a type. They contain more than 6 atoms of carbon per molecule. The heavy hydrocarbons are gases, such as ethylene, acetylene, and their analogues. In making this analysis the hydrocarbon

vapors were first removed and determined, then the heavy hydrocarbons were absorbed, leaving only CH_4 of the strictly organic compounds to be determined. What percentage of this material exists in the rock in the true gaseous state is impossible to tell, though it is probably not a very large proportion. Most of the gas, as the analysis indicates, came from the distillation and decomposition of various volatile hydrocarbons which give to the oil-rock its name and precipitating properties. None of my analyses, with the exception of one of highly bituminous shale from Tennessee, have shown either hydrocarbon vapors or heavy hydrocarbons present. The excessive volume of the gas, 57, as against an average of 4 volumes per volume of rock, and the usual amount of H_2S and CH_4 are the other notable features of the oil-rock gas. CH_4 rarely exceeds 5 per cent in igneous or sedimentary rocks unless manufactured in the combustion tube from organic compounds present. In this case heavy brown tars were also evolved.

A microscopic examination of slides of the same material made by Mr. David White leads to the following conclusions:

Thin sections of the light chocolate shales show them to contain minute, flattened, generally oval, and discoid translucent bodies of a brilliant lemon-yellow color and highly refractive, the birefringence, as determined by F. E. Wright, being 1.619. These yellow bodies, varying from 8 to 62 microns in horizontal diameter and 5 to 20 microns in vertical, usually thinly lenticular and irregularly rounded at the edges, but often nearly oval, are, in vertical section, seen to lie horizontally matted with other sediments and with crystals of later formation, precisely like the matting of forest leaves beneath the winter snow. While varying greatly in size they accommodate themselves topographically when overlapping or surmounting the coarser rock material and seem to preserve their individuality even when apparently in contact. They are incredibly numerous, constituting over 90 per cent of the rock mass in the richest layers.

Upon proper microscopical manipulation the larger of the yellow bodies appear to include a number of horizontally oval figures, characterized by an extremely narrow and usually obscure marginal ring and a small, roundish, or slightly irregular, denser, and often darker-colored mass near the center. These figures, averaging about 8 microns in length and 5 microns in width, are suspended in the translucent yellow bodies, in which they are similarly compressed horizontally. They are regarded as probably corresponding to the contours of collapsed and flattened unicellular plants, the outer ring representing the cell boundary, the inner, denser portion, the residual contents of the cell, whose original gelosic envelope is preserved as the bright, lemon-colored, environing mass. The smallest yellow bodies appear to have contained a single oval, the larger ones several. The yellow bodies are therefore interpreted as the fossil remains of microscopic, unicellular, gelosic algæ, apparently comparable to the living Protococcales. They appear to have been somewhat enriched in bitumen after the cessation of bacterial disintegration, which, in the buff shades, does not seem to have progressed sufficiently to form a noticeable fundamental jelly.

The black oil-shale differs from the light chocolate and buff rock chiefly by its deeper color, probably due to greater humification and bituminization of the gelosic bodies, and more particularly by the suspension of the latter in a dark-brown groundmass or fundamental jelly. The details of the oval figures and the included, denser, small, central masses are much more strongly defined and generally more deeply colored. The slightly smaller size of the yellow bodies in the black shale is regarded as due either to greater shrinkage under the influence of the bitumen or to more extensive bacterial reduction. The dark-brown groundmass appears to consist of a fundamental jelly, largely filled with minute mineral matter and granulose fragmental débris or wreckage due to destructive bacterial action on the gelosic bodies, many of which, like the small fragments of larger associated algæ, are greatly corroded. Many of the gelosic bodies were doubtless completely decomposed. To this bacterial work on the organisms is due, in the judgment of the author, the essential character of the somewhat humified fundamental jelly itself, to which there has probably been accession of attracted bitumen. The more extended bacterial action seen in the black

shales is interpreted as antecedent and casually related to the greater bitu-
minization of the organic matter rather than as merely incidental or
accidental.

The oil-shales owe their volatile hydrocarbon contents either directly
or indirectly to the fossilized residues, interpreted as to the remains of
microscopic algæ, which locally composed over 90 per cent of the sedimentary
material. These pelagic or floating algæ fell in prolonged showers in quiet
or protected areas where the water was presumably somewhat charged with
tannic or humic solutions conducive to the early arrest of anærobic bacterial
decomposition. Possibly the bacterial action was arrested by its own prod-
ucts. The original deposits were doubtless several times as thick as those
now remaining, since it is probable that the organic residue represents as
little as one-twelfth of the original volume.

The Ordovician, like the Carboniferous gelosic algæ, appear to have
exercised an attractive or selective influence on bituminous compounds, par-
ticularly those of illuminant values, and to have consequently been perma-
nently somewhat enriched. Portions of their hydrocarbon contents have
doubtless been lost at various periods, and the great shrinkage of the shale
which caused the collapse of the overlying limestone strata may have marked
the first of these periods of hydrocarbon reduction. Presumably accelerated
loss occurred at all times of rock folding in the region. Such an occasion
might be favorable for the deeper zinc deposition.[17]

Results of later analysis are as follows:

Analyses of oil-rock[18]

	Capitola mine	Big Jack mine
Moisture	5.75	8.10
Volatile	22.08	18.65
Fixed carbon	4.23	3.41
Ash	67.93	69.84
	100.00	100.00
Sulphur	1.92	1.94
Calories	10.20	9.62
British thermal units	1836	1732

GAS DETERMINATION

The following are the results of a destructive distillation test on the
sample of oil-rock received April 28, 1909, from Platteville, Wis. The rock
as received was crushed to buckwheat size, 500 grams (1.11 lbs.), placed in
an iron retort and heated in a furnace previously brought to 1080°C., until
practically all the gas was evolved.

Gas yield, cubic feet per ton at 0°C and 30 in. mercury pressure and
dry: 6130 cu. ft.

Composition of average gas as collected

CO_2 and H_2S	35.4
Illuminants	2.2
O	1.3
CO	43.6
CH_4 etc.[a]	3.0
H	7.5
N	7.0
	100.00

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[17] Bain, H. F., U. S. Geol. Survey Bull 294, pp. 26–27, 1906.
[18] Furnished by the U. S. Bureau of Mines, through David White.
[a] Includes all hydrocarbons of CnH_{2n+2} type.
(N in this gas = 1.93.)

The large amount of CO_2 in the gas is to be explained as resulting from the decomposition of calcite or other carbonates in the rock. Probably the CO is in some degree formed by the reduction of CO_2. There is a considerable amount of hydrogen sulphide in the gas as shown by lead acetate paper. The gas burns freely with a colorless flame. The solid residue from the distillation is gray-black in color and can be readily powdered. A certain amount of dark, thin oil was driven over in the test along with water.

OIL DETERMINATION

The sample was subjected to extraction with benzol to remove all naturally occurring petroleum oils, paraffines and asphaltums.

A second sample was subjected to distillation under atmospheric pressure, and a third sample distilled under a vacuum of 12 mm., with no appreciable increase in yield of oil of the vacuum distillation over the distillation under normal pressure, showing that but a small quantity of matter was present as a true oil.

The total distillate of oil came over between 325°C., and 425°C., both under normal pressure and under 12 mm. vacuum, accompanied with much yellow-brown fog due to decomposition, showing again that there was no appreciable quantity of naturally occurring oil present.

The quantitative results yield:

Natural oil by extraction with benzol...................................	0.36
Oil of destructive distillation, closely resembling creosotic oils formed by destructive distillation of woods................................	2.86
Loss due to destructive distillation of vapors and gases of destructive distillation	1.91
Water	8.71
Mineral residue, black and friable, containing a small amount of carbonaceous matter..	6.16
	100.00

The sample of "oil-shale" submitted cannot be made to yield commercially more than 5.13 per cent of oil even by the most refined methods of destructive distillation and will probably yield not more than 3.22 per cent of oil.

This oil will make a good fuel, probably a wood preservative, but on account of the excessive amount of mineral matter present, the shale will serve better as a gas producing material.

MAQUOKETA SHALE

Good exposures of the Maquoketa shale are few and are limited to the margins of the lead and zinc district, the best exposures being found at Elizabeth, Stockton, Scales Mound, Apple River, etc., and in southeastern Iowa, at Dubuque, Julien, and Graf.

The lower portion of this formation as it appears at Elizabeth, Apple River, and Stockton, Ill., and Julien, Ia., consists of alternate bands of a bluish shale and limestone as shown in Plate IV, *A*. At the Granville mine, north of Scales Mound, about 30 feet of the upper portion of the shale formation are exposed to view. Here also it consists of a light blue shale containing 2- to 4-inch beds of limestone, although these interstratified bands are more widely spaced than in the lower portions of the formation. In these shales pieces of sphalerite easily discernible with the naked eye occur associated with pyrite and barite.

The following sections were made by Calvin and Bain:[19]

Section of Maquoketa shale at Graf, Iowa

		Ft.	In.
17.	Drab to black, argillaceous, unfossiliferous....................	2	
16.	Sixth Orthoceras bed; brownish, hard, granular, nonfissile shale, with numerous specimens of the minute, brad-like shells of *Coleolus iowensis*, some small gasteropods, a few specimens of *Orthoceras sociale*, together with cephalic shields and pygidia of *Calymene mamillatus*.....................................	1	2
15.	Shale, drab, very fissile, somewhat sandy, no fossils...........	1	4
14.	Fifth Orthoceras bed; light brown, earthy, nonlaminated, rather hard layer, which some writers have described as limestone; not very calcerous; crowded with shells of *Orthoceras sociale*, which are generally crushed and otherwise imperfect, some of the partially decomposed shells still retaining the original nacreous luster...	1	
13.	Fissile, slaty shale, dark gray in color, containing many blade-like or sheath-like impressions of *Spatiopora iowensis* Ulrich..		6
12.	Fourth Orthoceras bed, lithologically the same as No. 14; *Orthoceras* very numerous and crowded, more perfect than in 14....		6–8
11.	Shale varying in thickness, dark gray in color................		1–3
10.	Third Orthoceras bed, resembling 12 and 14....................		10
9.	Thin bed of dark, fissile shale; irregular as to thickness, in some places reduced to a mere parting...........................		1–3
8.	Second Orthoceras bed, lithologically like 10, 12 and 14.........	1	
7.	Shale, dark brown, imperfectly laminated, rather coarse grained and earthy, crowded with *Diplograptus peosta*................		5
6.	First Orthoceras bed, like No. 8...............................		4–8
5.	Shale, brown, fissile, fossiliferous............................		7
4.	Shale, earthy, granular, nonlaminated, with many comminuted fossils and perfect shells of *Coleolus iowensis*, *Murchisonia gracilis*, *Liospira micula*, and other species..................	2	
3.	Shale, dark brown, nonfissile, with a species of *Lingula* three-eighths of an inch long and one-fourth of an inch wide........	2	
2.	Shale, dark bluish-black, fissile or slaty, containing large numbers of *Leptobolus occidentalis* and two species of *Lingula*....	2	2
1.	Shale, brown or black, nonfissile, fossils rare, occasional specimens of a *Lingula* half an inch long and three-eighths of an inch wide...	6	

Apparently the lowest beds of the Maquoketa are not represented in this section. These, together with much of the Graf section, are shown in the following, also measured by Calvin and Bain.

Section of Maquoketa shale near Hills Mill, Dubuque County, Iowa

		Ft.	In.
30.	Blue and green plastic clay shales, concealed in slope, except at contact with No. 29; thickness not measured..................		
29.	Shale, yellowish, weathering to plastic clay....................	1	
28.	Indurated, stony beds, yellow................................		3
27.	Shale, laminated, fissile, yellow..............................	2	
26.	Dark drab, nonfissile shale containing a few specimens of a small *Orthoceras*, a different species from *O. sociale* Hall............		3
25.	Fissile, slaty, bluish shale, weathering yellow..................		6
24.	Yellow, stony, calcareous, nonlaminated bed, with some specimens of *Murchisonia gracilis* and numerous small lingulas....	3	
23.	Drab, slaty shale, equivalent to Nos. 16 and 17 of Graf section...	2	
22.	Shale	1	
21.	Fifth Orthoceras bed; 40 feet above base of the formation......	1	

[19] Geology of Iowa, vol. 10, pp. 180–182, 1900.

Section of Maquoketa shale near Hills Mill, Dubuque County, Iowa—Concluded

		Ft.	in.
20.	Shale, equals No. 13 at Graf....................................		6
19.	Fourth Orthoceras bed, equals No. 12 at Graf..................		6
18.	Thin seam of shale, equal to No. 11 at Graf....................		2
17.	Third Orthoceras bed, equal to No. 10 at Graf.................		10
16.	Shale, equal to No. 9 at Graf.................................		2
15.	Second Orthoceras bed, equal to No. 8 at Graf.................		10
14.	Dark, fissile shale..		3
13.	Nonlaminated shale, with shells of *Murchisonia gracilis*........		3
12.	First Orthoceras bed, equals No. 5 of Graf section.............		6
11.	Brown, fissile shale, equals No. 5 of Graf section.............	1	
10.	Nonlaminated, fossiliferous bed, equal to No. 4 at Graf.........	2	
9.	Brown, fissile shale, equal to No. 3 at Graf....................	2	
8.	Earthy, fossiliferous shale, not represented at Graf............		2
7.	Blue, slaty shale, with the fossils of No. 2 at Graf.............	1	2
6.	Hard, yellowish, barren shale................................		3
5.	Laminated shale with the large lingulas of No. 1 at Graf.......	13	
4.	Bluish or drab, laminated shale, with traces of graptolites and numerous specimens of *Leptobolus* and *Lingula* in the lower part; upper part barren......................................	8	
3.	Bluish, unfossiliferous, laminated shale.......................	8	
2.	Shale, variable in color and texture, but in general nonlaminated and coarse; very fossiliferous; carries a small species of *Orthoceras*, *Liospira micula*, *Pleurotomaria depauperata*, *Hyolithes parviusculus*, *Cleidophorus*, and *Ctenodonta fecunda;* the last-named species very common................................	2	
1.	Upper beds of the Galena limestone, showing the usual thin layers which become progressively thicker from above downward; exposed in vertical walls in bank of stream............	15	

The lower portion of the shale is, at least in places, more bituminous than the upper, and it also carries a greater amount of iron sulphide, which may be more or less oxidized. At places the shale becomes very bituminous, as at Eleroy, Savanna, and Mt. Carroll, where it contains as high as 15 per cent carbon and 22 per cent total conbustible matter. It was this character that first led to its consideration as a possible source of the ores, which consideration has been further strengthened by the finding of ore minerals in it at Eleroy and Mt. Carroll, and in the light blue shale at Elizabeth, Stockton, Scales Mound, Hanover, Galena, etc. Analyses of the Maquoketa shales showing the presence of organic matter, lead and zinc are shown on pages 83 and 84.

NIAGARA DOLOMITE

This formation was named by Hall in 1858 after the Niagara limestone of New York because it apparently represented a continuation of that formation and, in general, contained similar fossils. That it is an exact equivalent of that formation now seems doubtful, since it probably represents a longer time interval. The area in northeastern Illinois underlaid by the Niagara dolomite is even smaller than that underlaid by the Maquoketa shale, although the general distribution of the two formations is similar. It is this dolomite which caps the mounds in the

mining regions of Illinois, Iowa, and Wisconsin, and by its protecting influence preserves them.

As exposed in this part of the State, the Niagara dolomite is of a light, yellowish-gray color, the shade depending largely upon the amount of weathering to which it has been subjected. It is essentially a thin-bedded, cherty dolomite, (Pl. VIII, *B*) locally absent, but having a maximum thickness of 150 feet, although nowhere showing its entire original thickness which was probably greater than 200 feet. In places the lower 50 feet consist of an earthy, nonfossiliferous dolomite which on weathering does not show the pitted structure so characteristic of the dolomites of the Niagara and Galena formations in general. Such beds are best exposed at the tunnel of the Chicago Great Western Railroad about 8 miles southeast of Galena, and are thought to be rather local in their occurrence. These beds may be indicative of an unconformity which is thought by many to occur between the Maquoketa and Niagara formations.

General section of the Niagara formation in Dubuque County, Iowa[20]

		Feet
7.	Upper quarry beds	20
6.	Cerionites beds	25
5.	Pentamerus beds	50
4.	Syringopora beds	65
3.	Chert beds	25
2.	Lower quarry beds	20
1.	Basal beds	15
		220

The weathered outcrops of the Niagara and Galena formations are in many respects rather similar (see Pl. VII), but are usually distinguished by their stratigraphic positions, their fossil contents, the usually more porous and less flinty character of the Galena, and the tendency exhibited by the Niagara beds to break into large joint blocks from 10 to 20 feet across, a feature which is not characteristic of the Galena dolomite.

According to Grant and Bain, the most abundant fossils of this formation are the corals, *Halysites catenulatus* Linnaeus; *Favosites favosus* Goldfuss; and *Favosites niagarensis* Hall; and a Brachiopod, *Pentamerous oblongus* Sowerby.

TERRACE DEPOSITS

During the Pleistocene period · when the great ice sheet covered nearly all the land area north of the Missouri and Ohio rivers, the drain-

[20] Geol. Survey of Iowa, vol. 10, p. 459, 1900.

age system of the non-glaciated area of the upper Mississippi Valley, of which the lead and zinc district is a part, was disturbed. The result was a filling of the stream beds with gravel, sand, and silt. Later, when the conditions became normal, these deposits were cut down in part, leaving as remnants here and there, portions of the alluvial filling. These are now the well-marked terraces along the Mississippi, Apple, and Galena rivers (Pl. IX, A). One of these is especially well exhibited (Pl. III) at Galena where the city park and part of the city itself is situated upon it. The terrace material consists essentially of laminated silts (Pl. IX, B), sand, and gravel of local origin (except in the case of the Mississippi), containing in places many small shells of such character as to indicate that the climatic conditions were not severe at that time.

At the mouth of the Galena River the terrace occurs at an elevation of about 645 feet above sea level, or about 55 feet above the level of the Mississippi. From this point it extends in a nearly horizontal position for about 10 miles up the Galena River to the town of Millbrig where it sinks into the modern flood plain.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The zinc and lead district comprises a part of the west limb of a large, low anticline with its axis extending through Wisconsin into Illinois in a direction slightly east of south and pitching in the same direction. This pitch of the fold gives the beds a gentle general dip to the south, which in southern Wisconsin averages about 20 feet to the mile and in Illinois from the State line to the south edge of the Galena Special sheet, a distance of 10 miles, about 17 feet to the mile. Such slopes are far too small to be determined except by leveling, especially when concealed by minor folds. The minor folds in Wisconsin have a general east and west strike, whereas those of Illinois strike more nearly east by north. A number of the larger of these folds have been discussed by Grant.[21] The district contains no known faults and probably no dips exceeding 10°. The greatest change in elevation of the oil-rock horizon is about 200 feet in a quarter of a mile between the Marsden-Black Jack and Twin Jack mines south of Galena.

FOLDS AND OIL-ROCK BASINS

The contour map of the oil-rock horizon based upon drill records, outcrops, and mining data has the appearance of a district which has been folded in two directions so as to form basins. (Compare Plate XXI

[21] Grant, U. S., Wis. Geol. and Nat. Hist. Survey, Bull No. XIV, p. 53, 1906.

A. Remnant of terrace along Hughlett Branch Creek.

B. Laminated silts of terrace formation at Grant's Park, Galena.
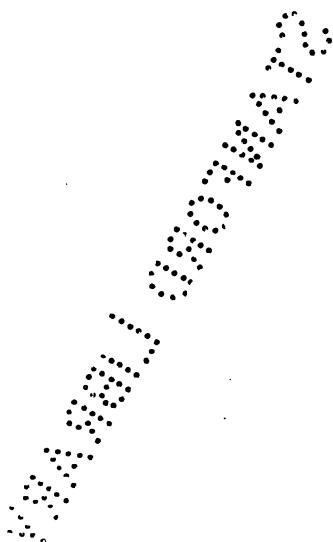
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in Pocket.) The presence of these structural basins at the Galena-Platteville contact was noted early in the history of the district, Chamberlin in his first report stating that there seems to be a connection between the ore deposits and the oil-rock basins. Just what portion of the inequalities are due to initial dip caused by the unevenly eroded surface of the Prairie du Chien dolomite, which lies unconformably below the St. Peter sandstone, and what portion to folding, is uncertain. That an unconformity exists between the St. Peter sandstone and the Prairie du Chien dolomite, and that a drainage system had been at least partially established before the deposition of the sandstone, seems certain. Yet it is not clear how these irregularities carried upward in an increasingly modified form by the deposition of the sandstone and limestone, could produce basins.

There is, in places at least, an apparent thickening of the oil-rock beds at the crests and troughs of the folds; a condition such as might result from the folding of a thin, incompetent bed of shale between two hard, competent layers of limestone, like the Platteville and Galena formations. However, the base of the Maquoketa shale, although varying in elevation from place to place, does not have the variation shown by the oil-rock. This indicates that either the oil-rock basins were formed only in part by folding or that the folding took place largely before the deposition of the shale. Grant[22] concludes that, "It is quite probable .... that in very many cases inequalities in deposition have been accentuated by folding since the rocks have solidified." Bain[23] finds a similarity between these basins and those found in Pennsylvania. "The Pennsylvania structure is explained as due to deformation produced by lateral compression, and in absence of evidence to the contrary it seems proper to consider the Wisconsin structure an expression of the same sort of forces."

It therefore seems logical to conclude that the contour of the oil-rock horizon represents a vertical projection of the erosion surface at the top of the Prairie du Chien dolomite modified by later sedimentation and folding.

JOINTS AND CREVICES

All of the formations exposed in the district, with the exception of the Maquoketa shale, show complicated systems of both vertical and dipping joints, the former predominating. When areas of sedimentary rocks are folded two sets of vertical joints are usually developed, a major set parallel to the strike of the fold and a minor set normal to this direction. In the summary of 1,342 crevices shown in the accompanying cut,

[22] *Idem.*
[23] Bain, H. F., Zinc and lead deposits of the upper Mississippi valley; U. S. Geol. Survey Bull. 294, p. 41, 1906.

it is seen that by far the greater number of crevices in the district have a general east and west trend, which is also the general trend of the folds and the oil-rock basins, showing rather conclusively that some relation exists between them, the vertical fractures apparently, in part at least, being due to tension and compression developed during folding. These fractures vary from a few inches to 1 mile or more in length, from a fraction of an inch to 3 or 4 feet across, and are limited vertically to a single formation.

Part of the inclined or dipping crevices have without doubt been formed in a manner similar to that outlined for the vertical crevices,


Total number of crevices 1342
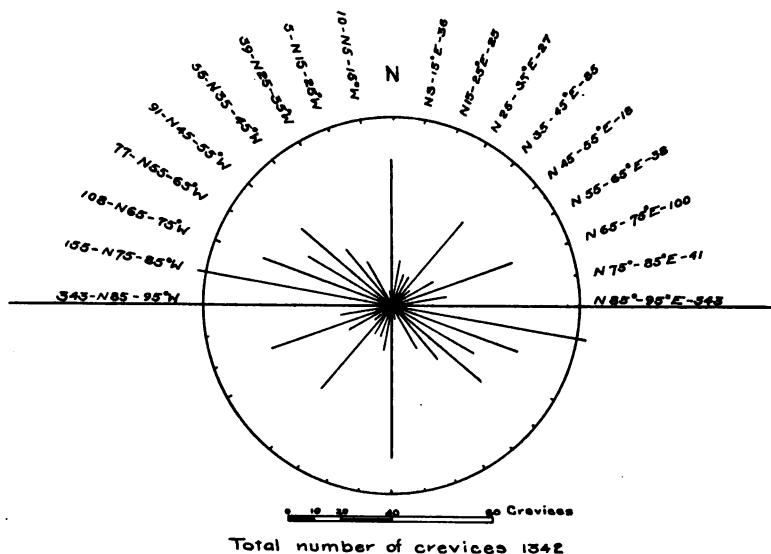
FIG. 3. Crevice chart—a summary of the strike of 1,342 crevices as shown on the crevice map, Pl. VII, U. S. Geol. Survey Bull. 294. The compass was divided into segments of ten degrees and the number of crevices falling into each segment totaled.

their inclined character being due to a lack of homogeneity in the rock they traverse, while others are the natural result of compression forces acting parallel to the beds. However, Bain seems to think that these classes of crevices differ in their manner of origin, and that the inclined crevices may be older than those which are vertical. Yet at the Pittsburg-Benton mine east of Cuba City, Wis., a vertical crevice continues to the oil-rock unaffected by the two inclined joints which branch off at different points, indicating that the vertical crevice is the older; while in other mines the vertical crevice ends by branching into inclined crevices, indicating simultaneous origin. Bain[24] believes that the inclined fractures

[24] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull 294, p. 64, 1906.

are due to an unequal distribution of the oil-rock, which, through decay, has resulted in an irregular settling or slumping of the overlying beds. Under such conditions rocks tend to break in the form of an arch, thus producing inclined fractures.

The predominance of east and west crevices is very apparent in the accompanying cut as is also the presence of quartering crevices. All of these directions are readily grouped into major and minor sets at right angles to one another, such as are ordinarily formed during folding. The symmetry of the figure is remarkable, and, were it not for the prominent N. 75° to 85° W. series, it would be almost perfect.

The coincidence between the most prominent direction of the fracturing and that of the major folding is strongly indicative of a relation between the two. As stated above, two sets of fissuring are usually developed in folds, a major set parallel to the direction of the major folding and a minor set normal to this, or parallel to the minor folding. It might be expected, therefore, that the relative abundance of these two sets of fractures would be roughly proportional to the degree of folding in these directions, or that the number and size of fractures formed by folding would vary directly with the degree to which the limbs of a fold are compressed. Therefore, roughly speaking, if the crevices have been formed largely by folding, the number of them parallel to the longer axes of the oil-rock basins should bear the same ratio to the number parallel to the shorter axis (normal to the first) as the average length of the oil-rock basins does to their width. Although it is true that by far the greatest number of crevices strike in a general east and west direction, the directions of the axes of a sufficient number of basins upon which to base a satisfactory comparison are not accurately known. Nevertheless, the ratio of the number of fractures in any two directions normal to each other, as shown in fig. 2, varies from 1: 1.85 to 1: 14.33, averaging 1: 4.41, whereas the ratios of the lengths to the widths of the oil-rock basins striking in the various directions varies from 1: 1.02 to 1: 20, averaging 1: 4.95, a fact which is at least significant.

CHAPTER III—ORE DEPOSITS

ORE AND ASSOCIATED MINERALS

The ores of this district are, in the order of their importance, those of zinc, lead, and sulphur. The ore minerals of zinc are sphalerite and smithsonite, although very little of the latter is now being produced, since it is limited in occurrence to deposits near the surface which have been largely worked out. The ore of lead is limited to galena, and the ores of sulphur are marcasite and pyrite, the production of which is very small in Illinois. Below are listed the minerals that are ordinarily found in this district:

Anglesite.—(Lead sulphate; $PbSO_4$; metallic lead 68.3 per cent; sulphur trioxide 26.4 per cent; lead oxide 73.6 per cent; specific gravity 6.3; color white to gray, transparent to opaque; hardness 3, about the same as calcite).—This mineral is reported to have been found, but its occurrence is questionable.

Barite, "heavy spar" of the miners.—(Barium sulphate; $BaSO_4$; sulphur trioxide 24.3 per cent; baryta 65.7 per cent; specific gravity 4.3 to 4.6; color and streak—color when scratched, white; readily scratched by steel).— In Wisconsin, Iowa, and Illinois, barite has been found at all horizons from the bottom of the oil-rock to the top of the Maquoketa shale. It is most abundant at the Gritty Six and Raisbeck mines near Meekers Grove, Wis.

Calamine.—(Zinc silicate; H_2ZnSiO_5; metallic zinc 54.23 per cent; zinc oxide 67.5 per cent; silica 25 per cent; water 7.5 per cent; specific gravity 3.4 to 3.5; color white; brittle; not quite so hard as steel).—Resembles smithsonite but is distinguished from it by not effervescing with acid. Quite common in zinc deposits of Missouri but not definitely recognized in this district.

Calcite, "tiff" of the miners.—(Calcium carbonate; $CaCO_3$; carbon dioxide 44 per cent; lime 56 per cent; specific gravity 2.71; crystals usually three or six sided; perfect cleavage breaking into rhombs; colorless; easily scratched by steel; effervesces in cold, dilute acid. Also known as calc spar, or spar).—This is the most common gangue mineral. In general the calcite is younger than the ore minerals.

Cerusite.—(Lead carbonate; $PbCO_3$; metallic lead 77.5 per cent; carbon dioxide 16.5 per cent; lead oxide 83.5 per cent; specific gravity 6.46 to 6.57. Sometimes this mineral is called white lead ore).—It usually occurs as small colorless crystals on the surfaces of cubes of galena. A number of good specimens of such crystals were obtained from the Northwestern mine near Millbrig.

Chalcopyrite.—(Sulphide of copper and iron; $CuFeS_2$; sulphur 35.0 per cent; copper 34.5 per cent; iron 30.5 per cent; specific gravity 4.1 to 4.3; scratched by steel; color brass-yellow).—Small quantities of this mineral have been reported from various places. Near Mineral Point and Gratiot, Wis., it exists in large quantity, the former deposit having been mined to the value of nearly half a million dollars. Malachite, cuprite, chalcocite, azurite, and native copper were found in the deposit near Gratiot, Wis., where they are apparently alteration products of chalcopyrite.

Dolomite.—(Carbonate of calcium and magnesium; $CaMg(CO_3)_2$; carbon dioxide 47.9 per cent; lime 30.4 per cent; magnesia 21.7 per cent; specific

gravity 2.8 to 2.9; effervesces in hot, concentrated hydrochloric acid. Good crystals are rare, have curved faces, and are usually less transparent than those of calcite).—Dolomite is found as small crystals lining druses in the country rock.

Galena, "mineral" of the miners.—(Lead sulphide; PbS; lead 86.6 per cent; sulphur 13.4 per cent; specific gravity 7.4 to 7.6).—In this district the galena almost invariably occurs in well-crystallized forms of which the cube is by far the most common. The cube with its corners cut by octahedral faces occurs on some crystals, and the rhombic dodecahedron has been noted by Hobbs[1] on others.

Galena is readily recognized by its cubic crystallization, high specific gravity, and a cubic cleavage so perfect that when a fragment of the mineral is struck by a light blow, it will break into six sided pieces, with a brilliant metallic luster on fresh fracture surfaces. In size the crystals vary from a fraction of an inch to a foot across, the larger crystals, which are known as "cog mineral," being characteristic of the "crevice" and "opening" deposits which exist near the surface. In contrast to this the smaller crystals, approximating one quarter of an inch in size, are termed "dice mineral." The term "sheet mineral" is also used for this ore when it occurs in thin layers. In the western states galena is the chief source of silver but that of the upper Mississippi Valley district contains but a small amount of this element, averaging about one and one quarter ounces to the ton of ore. Two or more ounces of silver are required to affect the price of the ore.

Hydrozincite, "zinc bloom" of the miners.—(Basic zinc carbonate; $ZnCO_3.2Zn(OH)_2$; metallic zinc 60 per cent; specific gravity 3.58 to 3.80; color white to gray; soft).—This mineral is not generally recognized in the district but is reported as being present at Linden, Wis., where it is found mixed with smithsonite which it closely resembles.

Limonite.—(Hydrous ferric oxide; $2Fe_2O_3.3H_2O$; iron 59.8 per cent; oxygen 25.7 per cent; water 14.5 per cent; specific gravity 5.0 to 5.5; color brown to yellow; secondary, usually formed by the alteration of pyrite and marcasite).—The quantity in this district is too small to be of economic importance as an iron ore, although some has been mined for this purpose near Durango, about 8 miles northwest of Dubuque, Iowa.

Marcasite and pyrite, "sulphur" of the miners.—(Iron sulphide; FeS_2; iron 46.67 per cent; sulphur 53.33 per cent; specific gravity—pyrite, 4.67 to 5.20; marcasite, 4.65 to 4.88. Crystallization of pyrite is isometric in cubes, octrahedrons, and pyritohedrons; of marcasite, orthorhombic in massive, globular, reniform, and other imitative shapes. Color of pyrite is a brilliant brass-yellow, of marcasite a slightly whiter brass-yellow, but both marcasite and pyrite may assume a tarnish causing them to resemble chalcopyrite in color, an effect, however, which is confined to the surface only).—These minerals are used in the manufacture of sulphuric acid.

Melanterite, "copperas."—(Hydrous ferrous sulphate ($FeSO_4+7H_2O$); color various shades of green becoming yellow on exposure; brittle; soft; taste sweetish, astringent).—This and zinc sulphate (probably goslarite) have been reported by Bain. However, both minerals are very soluble in water so that their occurrence never can be common.

Psilomelane, "Wad" of the miners.—(Hydrous oxide of manganese; MnO_2+Aq; specific gravity 3 to 4.7).—This mineral is found in a soft, amorphous, black powder, and in places in hard lumps. It is probably derived from the alteration of a sulphide. The most abundant occurrence of this mineral is near Gratiot,[2] Wis.

Quartz.—(Silica; SiO_2; oxygen 53.3 per cent; silicon 46.7 per cent; specific gravity 2.65; colorless; transparent; harder than steel; no cleavage; occurs in six sided crystals).—This mineral is not associated with the ores but is scattered through the country rock as small grains and is present as druses in the walls of cracks. Chert, a hydrous form of quartz, is found in considerable quantity in the dolomites of the region.

Selenite or gypsum.—(Hydrous calcium sulphate; $CaSO_4+2H_2O$; sulphur trioxide 46.6 per cent; lime 32.5 per cent; water 20.9 per cent; specific

[1] Worthen, A. H., Geology of Illinois, vol. 1, p. 144, 1866.
[2] Cox, G. H., Copper in southwestern Wisconsin: Min. & Sc. Press, vol. 99, No. 18, p. 529, 1909.

gravity 2.32; colorless; transparent; soft; streak white; perfect cleavage, cleavage flakes not being flexible like those of mica).—In this region selenite is an uncommon mineral occurring in small crystals which are thought to have resulted from the action of some sulphate upon calcium carbonate.

Smithsonite, "carbonate," or "drybone."—(Zinc carbonate; $ZnCO_3$; metallic zinc 52.06 per cent; carbon dioxide 35.2 per cent; zinc protoxide 64.8 per cent; specific gravity 4.30 to 4.45; crystallization in the rhombohedral group of the hexagonal system).—The crystals of smithsonite as developed in this district are so small that their forms can not be recognized. The occurrence of this mineral is limited to deposits near or above the ground water level where it seems to be a secondary mineral and to show in places a marked tendency to replace other minerals such as calcite, galena, and sphalerite, retaining the crystal forms of these minerals and thus forming what are known as pseudomorphs. It has been found largely in the openings and crevices where it exists in two varieties, one a light, massive variety and the other, which is the more common, a yellowish or brownish, porous mass, resembling pieces of dry bone, from which character it derived the name "dry bone."

Sphalerite, "jack" of the miners.—(Zinc sulphide; ZnS; zinc 67.15 per cent; sulphur 32.85 per cent; specific gravity 3.9 to 4.1; cleavage dodecahedral, highly perfect; streak brownish to light yellow).—This mineral is also called "zinc blends," or "blende," "black jack," "resin jack," and "strawberry jack;" the black jack being the very dark variety; the resin jack, the somewhat transparent crystals resembling resin; and the strawberry jack, the crystals about the size of a strawberry, which are found in clay. Sphalerite varies in color from a light straw-yellow through a reddish somewhat transparent variety to a jet black, the color depending largely upon the amount of iron contained. Whereas it tends to crystallize in tetrahedrons and rhombic dodecahedrons, the crystals are usually so intergrown and distorted that these forms are not easily recognized. However, where they have grown unattached to the wall rock as in clay beds good tetrahedrons and some more complicated forms have been found.

Sulphur.—(Native sulphur; S; specific gravity 2).—Sulphur has been found in Wisconsin in fractures and openings in the Galena dolomite, but only in small amounts. These deposits are said to have been limited to less than a barrel of pulverent sulphur. This free sulphur is due apparently to the alteration of iron pyrite. Rumors are spread from time to time concerning the discovery of sulphur, but these are invariably due to the misunderstanding caused by the local use of the term "sulphur" for iron sulphide.

MODE OF OCCURRENCE

VERTICAL AND HORIZONTAL ARRANGEMENT OF MINERALS

A general arrangement of the ores in horizontal zones is apparent throughout the district. Galena is found in its characteristic position near the surface, at or above the water table, grading into iron sulphide at the extremities of the deposit both below and on the sides. Variations from this rule are many, for galena has been found in small amounts with practically all the zinc ores, as is some iron sulphide; whereas smithsonite, the secondary zinc ore, has been found in quantity above the water level.

There is also a general order of deposition of these minerals on the wall rock, which, according to Grant,[1] is (1) marcasite, (2) sphalerite, (3) galena, and (4) calcite. Here also many variations occur, although a film of marcasite is almost invariably found next to the wall rock.

FORMS OF ORE DEPOSITS

In this district the openings which carry ore have been designated as "verticals," "openings," "flats," and "pitches." Minor amounts of ore occur along joint planes and in some of the very porous portions of the Galena dolomite, the latter being called "honeycomb," "sprangled," and "disseminated" deposits.

CREVICES

Crevices are nearly vertical fissures that have been formed almost entirely by the enlargement of fractures by solution and which vary from a fraction of an inch to 6 feet in width, from a few feet to more than a mile in length, and are limited vertically to the thickness of the Galena formation, thus differing from ordinary fissures and fissure veins, a fact in recognition of which Whitney[2] gave them the name of "gash" veins. These openings are known as "verticals" and their ore bodies as "crevice deposits." (See Pl. X.) They strike in all directions, but their most common trend in the major lead and zinc district is in a direction a

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[1] Grant, U. S., and Burchard, E. F., U. S. Geol. Survey Geol. Atlas, Lancaster and Mineral Point folio (No. 145),p. 12, 1907.
[2] Geological Survey of Iowa, vol. 10, p. 502, 1900.

little north of west, and in the Illinois portion of the district a little north of east, this corresponding to the strikes of the oil-rock basins.

Those crevices which strike nearly east and west are locally known as "east and wests," those striking nearly north and south, "north and souths," and the quartering crevices, "10-o'clocks," "2-o'clocks," "4-o'clocks," etc., depending on the time of day at which the sun shines into them or is in their lines of strike. The term "range" is applied to an ore-bearing crevice or to two or more parallel ore-bearing crevices. The ore in these crevices is usually the coarsely crystalline variety known as "cog mineral," although the crevices may be lined or completely filled with zinc ore, especially in the lower portions.

OPENINGS

In general, openings are of a cavernous nature and characterize the upper half of the Galena formation. In most cases they have been
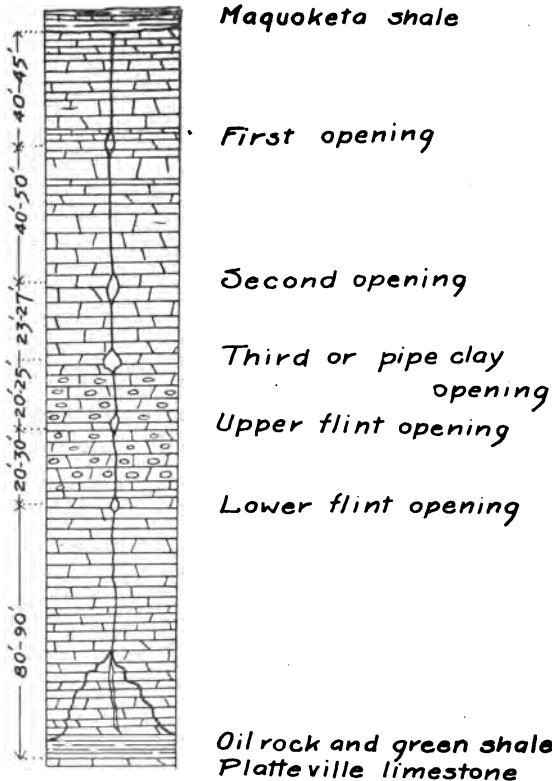
FIG. 4. Columnar section of the Galena limestone showing relative positions of openings.

formed by water passing along a crevice and dissolving certain layers or beds more than others. This may be due either to the presence of a

Close spacing of crevices in the old California diggings.

soft or more soluble bed or to the fact that a clay seam limited and concentrated the water circulation. Openings have been recognized at five horizons (fig. 4), but these horizons are constant only within small areas. Another opening is sometimes developed about 20 to 25 feet below the highest of the more common ones, which is then termed the second opening. Usually not more than three openings will be found in a given vertical section.

The term "opening" is sometimes applied to certain horizons within the Galena dolomite at which the ore is more likely to occur than at other horizons which neither are, nor have been, cave-like openings. This is especially true of the "lower flint opening" and the "glass-rock opening" in the Platteville limestone. (See Pl. XI.) Openings are usually lenticular in vertical cross-section. They vary in width from that of an ordinary crevice to 35 feet (openings even wider than this have been reported from the New California diggings), and may be 500 feet or even a mile in length. Either the vertical or horizontal dimension may be the greater.

The greater portion of the ore was deposited as a lining of the walls, but, because of the weight of the ore and the weathering of the dolomite to which it was attached, much of it has fallen into the opening to be succeeded by other coatings which may also have become detached, so that the openings are usually more or less filled by loose pieces of ore imbedded in dolomitic sand and dark clay, washed in from the surface. Some of the fragments of dolomite in the openings are completely coated with ore, showing that it was not all deposited upon the wall rock. Although galena is the most characteristic ore in these deposits, they also contain in places sphalerite, its alteration product, smithsonite, macasite, and limonite which is locally known as ochre. Such deposits are now rare, having been exploited during the early mining days of the district, but they are well represented at the present time at the Hoosier mine north of Galena. (See Pl. XI.)

FLATS AND PITCHES

The bedding planes of the Galena dolomite are in most places apparent, due mainly to solution, but locally to both solution and slump. When such nearly horizontal openings are mineralized they are called *flats*. Scattered through the formation are also many inclined joints or fractures to which have been applied the name *pitches*. Although both of these structures occur throughout the Galena dolomite, their characteristic mineralized occurrence is limited largely to the lower half of the formation. Vertical crevices in many cases branch in depth into two

crevices dipping in opposite directions. These, together with the mineralized flats between them, are the home of the zinc ore and constitute the so-called "flats and pitches" deposits of the upper Mississippi Valley lead and zinc district. The pitches start at about 100 to 150 feet above

Fig. 5a, 5b, and 5c.—Various types of flats and pitches
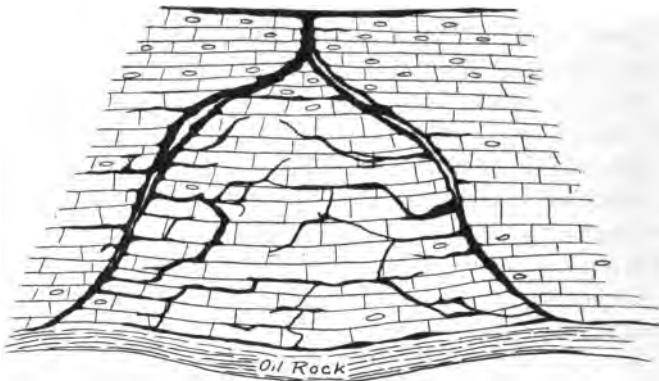

FIG. 5a. Both pitches equally developed.
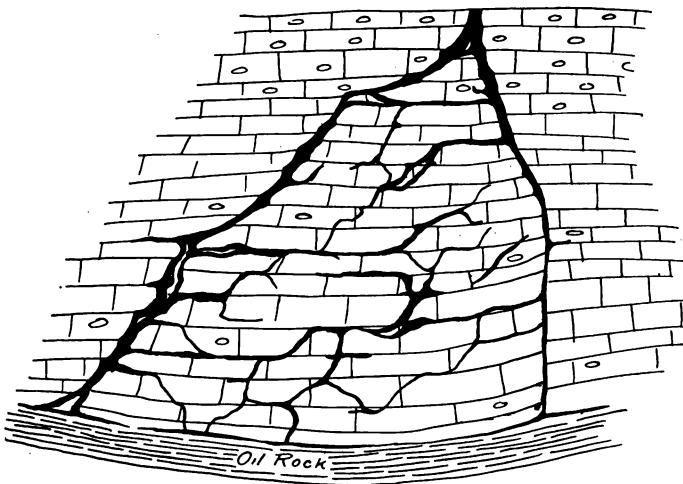
FIG. 5b. One pitch better developed than the other.

the oil-rock and reach it at points from 300 to 500 feet apart laterally and 500 to 1000 feet lengthwise; but on reaching the oil-rock the dip changes abruptly and the pitches flatten out and disappear (fig. 5a, 5b, and 5c).

West end of Hoosier mine showing character of openings.

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The two main pitches often show a tendency to encircle the oil-rock basins and join each other in the form of an ellipse; or they join at one end only to form a horse-shoe in horizontal section. It should be born in mind, however, that the Galena formation is not homogeneous, that the folding and dip of the beds are not regular, and that mineralizing solutions and precipitating agents have not been present everywhere, so that irregularities are the rule and not the exception. The pitches may join at one end only, or not at all; a pitch may narrow and apparently die out, only to develop again farther on; one pitch may be larger and better mineralized than the other, or one may be missing entirely; thus the pitches vary in many ways.
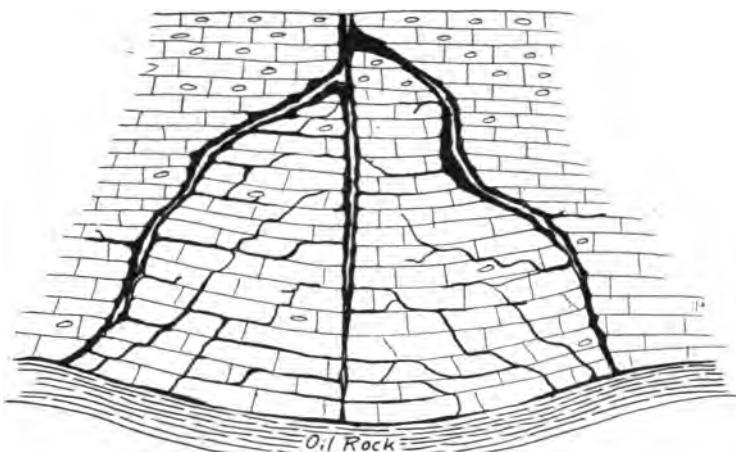
FIG. 5c.   Vertical crevice extending to oil-rock.

The subsidence of the part of the rock between two pitches, together with subsequent solution, have in places so enlarged the joints and bedding planes, that, if mineralized, the whole body of rock, locally known as the "core ground," may constitute a workable ore body.

It has been shown that the oil-rock since its formation has shrunk an amount varying between 1 and 12 times its present thickness, and Bain[3] has explained the flats and pitches as being due to the slump of the oil-rock in what are known as the oil-rock basins, thus depriving the overlying beds of their support at these points and causing their fracturing in the form of an irregular arch (Pl. XII). Unquestionably the main portion of the shrinkage of the oil-rock took place immediately after its deposition, so that only a fraction of the total shrinkage was effective after the Galena formation had been consolidated. Fractures

[3] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull 294 p. 64, 1906.

in the ore bodies filled with secondary ore and calcite show that some movement has taken place in the beds since the deposition of the ores. Field observations cast some doubt as to the adequacy of the oil-rock slump to account for many of the flats and pitches. It is suggested that solution has played an important part in the process, probably in conjunction with oil-rock slump, and it may be that the tendency of folding to relieve the upper beds of their support at the crests and the troughs of the folds, may have been influential in causing stresses in them which later resulted in the production of cracks.

HONEYCOMB DEPOSITS

At places the ore is found scattered through the dolomite, filling small irregular openings due to solution, brecciation, or both. The openings vary in diameter from one-quarter to two inches and the deposit grades into what is known as "disseminated" ore on the one hand and "sprangled" ore on the other, the latter name being applied to the ore that occurs in the larger and more angular openings. Galena, sphalerite, and iron sulphide are all found in these deposits.

DISSEMINATED DEPOSITS

Truly disseminated ores are limited almost entirely to the oil-rock and clay beds, although a small amount is found in the more organic beds of dolomite. However, in this district the name is often applied to deposits which simulate the honeycomb deposits but in which the ore particles are small. In such cases, the ore occurs almost without exception as a filling of small openings and fractures and not as true replacements of the rock as is usually inferred from the term "disseminated." Galena, sphalerite, and iron sulphide occur in this manner, but deposits of the last two are the more abundant.

RELATION OF ORE DEPOSITS TO TOPOGRAPHY AND STRUCTURAL FEATURES

If we assume that the ores have been deposited from water solutions derived from the surface, it necessarily follows that topography and structure have each played an important part in the location of the ore deposits, for one has controlled the movement of the water above the surface and the other that below it. It also follows that logical conclusions as to the probable locations of ore deposits can be drawn only by a consideration of these two factors acting together. Thus, if the mineralizing solutions have come from above, as is believed by the

Flats and pitches developed in a stone building.

author, the best possible structural conditions might be impotent to produce an ore deposit without a concentration of the mineralized solutions by surface features, and vice versa.

Almost without exception the ores occur along fractures which have been enlarged by solution. These fractures not only control the water circulation within the Galena dolomite, but also afford openings within the Galena dolomite in which ore may be deposited. The topographic features determine largely into which of these fractures the solutions shall be concentrated, but the shape, size, and point of outlet of the fractures determine largely whether or not the ore shall be deposited from the solution passing through it.

Chamberlin early recognized a tendency on the part of the ore to favor the oil-rock basins, a fact which has been emphasized by later writers. Although there is undoubtedly such a tendency on the part of the ore bodies, many of them occur on the limbs of the folds and some even on the oil-rock ridges. It has been pointed out that if the ore has been carried in solution, anything which controlled these solutions would also control the ore deposits. If, therefore, as is natural, the water tends to flow downward into these impervious, pitching troughs and along the openings such as the "verticals," "flats," and "pitches," which occur most abundantly in these basins, it is most natural that the ore deposits formed by these waters should also show a tendency to develop in these basins.

To prove that this relation between the ore deposits and the oil-rock basins favors the proposed hypothesis rather than that advanced by Bain and others, it has been shown that there is, in many cases, thick oil-rock without flats and pitches and without ore; that there is thick oil-rock outside the oil-rock basins; that there are oil-rock basins without ore; and that, although most of the mineralized flats and pitches occur within the oil-rock basins, such flats and pitches are found on the oil-rock ridges, or anticlines, as at the Dutch Hollow mine east of Potosi, Wis.; also that one of the most famous mines of the Wisconsin district, the Baxter, is located on top of one of the most prominent anticlines in the district and that this deposit tends to follow down the slope of the hill (drainage slope). Further, it has been shown time and time again, although apparently but little noticed, that a deposit of zinc connected with a deposit of lead near the surface, does not necessarily directly underlie the lead deposit, but almost invariably lies to the side of this upper deposit in the direction of the drainage, thus showing that the ore bearing solutions were moving downward along the natural drainage channels. This is well shown by the Vinegar Hill mine north of Galena, Ill., and the Frontier mine at Benton, Wis.

It is therefore concluded that there is a close relation between the ore deposits and the structural features of the district, but only so far as these features have controlled the circulation of the ore-bearing solutions and afforded openings in which the ores have been deposited.

This question is the most vital question which now confronts the mining men of the district, and prospecting cannot be carried on intelligently without its careful consideration. In general, it may be said that the ore has favored such openings as strike in a direction transverse to that of the surface drainage, as these ponded the water and checked its flow. Crevices which strike parallel to the hills are thus often mineralized, but those normal to this direction are usually barren, unless the hill slope is very gentle.

In the consideration of the flats and pitches deposits, the same two conditions are important, i. e., a concentration of the mineralized solutions largely by surface configuration and the presence of suitable openings to receive the solutions and in which the ores may be deposited. The importance of the relation of the strike of the openings to the direction of the drainage decreases with depth, and a previous surface concentration of the solutions is not so necessary in the case of the flats and pitches, because these occur largely within the oil-rock basins which tend to concentrate the underground water circulation. In applying the above statements it is well to remember that the surface drainage of the present is not necessarily that of the past and that all of the surface solutions were probably not of the proper composition to cause mineralization.

CHAPTER IV—DESCRIPTION OF MINES AND PROSPECTS

GENERAL STATEMENT

An attempt is made to describe briefly such mines and prospects of the district as are sufficiently developed to warrant consideration. The past has witnessed the development of a large number of important mines, of which there is now nothing to be seen except fallen-in shafts and overgrown dumps. Descriptions of such mines as are not included in this paper can usually be found in the older reports. Some of the mines described are not now open to examination. In such cases the descriptions have been written from data obtained from other reports and from such persons as were directly connected with the mines during the period of their operation.

GALENA DISTRICT

VINEGAR HILL MINE

The Vinegar Hill mine, (Pl. XIII, *A*) is situated in the NE. ¼ SW. ¼ sec. 21, T. 29 N., R. 1 E., Vinegar Hill Township, about three-fourths of a mile south of the Illinois-Wisconsin line. It is located in both topographic and structural depressions and the valley slopes on three sides are covered with pits from which lead ore was extracted in quantity during the earlier days of the district. The present shaft was sunk in 1904 near the intersection of an "east and west" and a "2-o'clock" crevice, the former dipping to the north and the latter to the southeast. These two crevices join in the form of a horseshoe so typical of flats and pitches deposits. Both pitches and most of the core ground are sufficiently well mineralized to constitute workable ore. The southwest ends of the pitches have not yet been defined, although deposits in the pitches and part of those in the core ground have now been worked for a distance of 350 feet from the shaft.

The ore is high-grade zinc blende with a small amount of galena and only a trace of iron sulphide. The mine is equipped with electric and steam power and with a 100-ton mill which is supplied with water direct from the mine, from which it is pumped at the rate of 600 to 700 gallons per minute. About 100 tons of zinc concentrates averaging from 50 to 51 per cent metallic zinc are produced each week. The method of mining by the use of high faces, deep holes, and large shots practiced in the disseminated lead region of Missouri is very successfully used in this mine. Because of its superior method of mining and

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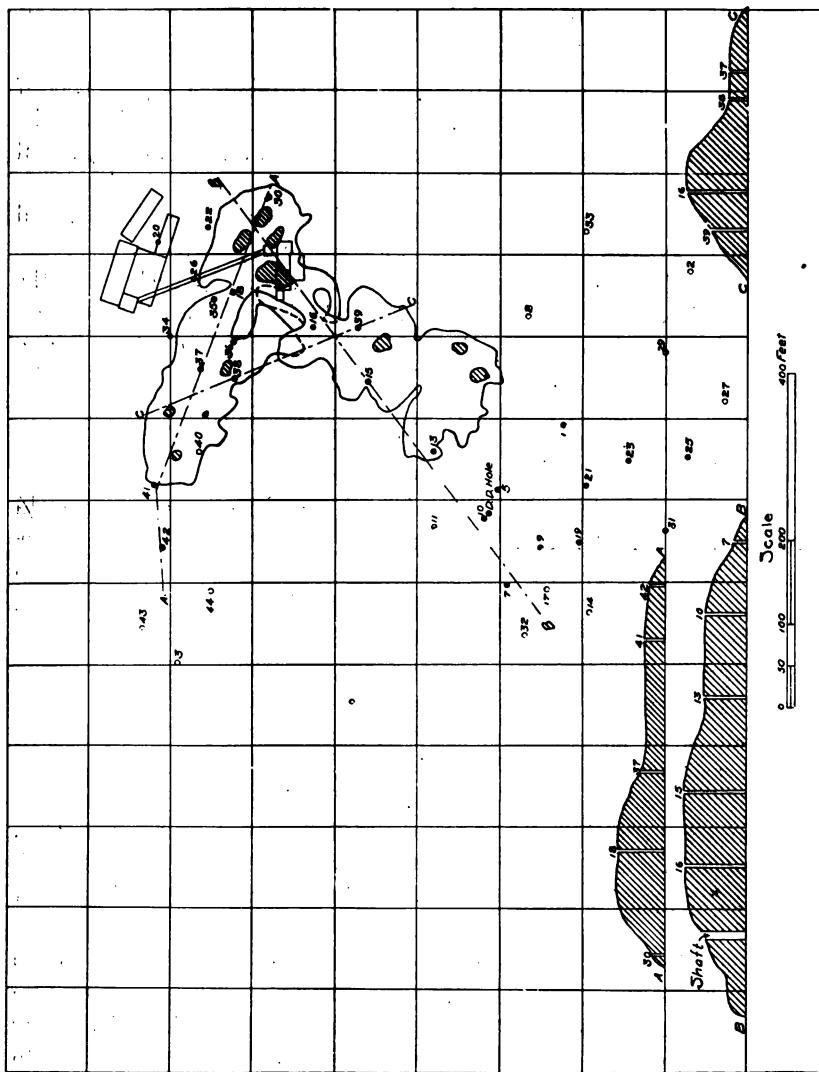
FIG. 6. Map of Vinegar Hill mine showing underground workings and sections, September 14, 1910. (Furnished by the Vinegar Hill Mining Co.)

A. Vinegar Hill mine.

B. Unity mine.

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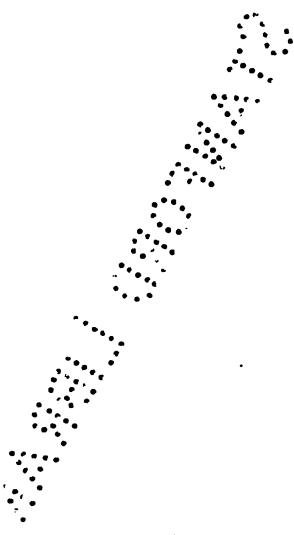
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milling, this mine is not only one of the largest producers of the upper Mississippi Valley district, but also one of the best managed.

UNITY MINE

This mine (Pl. XIII, *B*) is situated about three-eighths of a mile northeast of the Vinegar Hill mine and is operated by the same company. The mill was started in May, 1910. It consists of three jigs which have a total capacity of 100 tons a day, and turn out about 65 tons of zinc concentrates per week which analyze about 45 per cent metallic zinc. Electric power is used for all purposes to which it is adapted. The mine is not sufficiently developed at the present time to determine the character of the deposit.

MARSDEN-BLACK JACK MINE

The Black Jack mine, (Pl. XIV, *A*) formerly known as the Marsden Lode and the Peru mine, is situated in the SW. ¼ NE. ¼, sec. 4, T. 27 N., R. 1 E., about 3½ miles south of Galena. This mine is of especial interest not only because of its large lead and zinc output in past years, but also because it marks the southern limit of profitable zinc mining in this district. It is therefore described in some detail.

These deposits were discovered in March, 1854, by Stephen Marsden while digging a ditch to clean a spring in the lower portion of the valley in which the Black Jack mine is now situated. In cleaning out this spring which had become clogged and contaminated, considerable "float" lead ore and a large mass of galena were found. It is reported that for twelve hours after the spring was opened the water was perfectly black, showing that it had been ponded in the rocks. After drifting on the lead for 20 feet, a cave 20 or 30 feet in diameter was encountered. The cave contained large amounts of sphalerite and galena coated with iron sulphide. "From this another vein led to an immense deposit in circular form, in some places fifty yards wide, and from the inner edge of this circle it was found that the mineral 'fell off,' on an angle of about 45 degrees. From the cave to the 'pitch' is a distance of about 75 yards. This mine has yielded probably 8,000,000 pounds of mineral and was worked from the time of its discovery in 1854 until 1868. Large quantities of blende had been raised and thrown away as worthless, but about 1860 it was found to be valuable. Mr. Marsden sold the first black jack from this mine at $12 per ton. Since that time he worked it for blende principally, taking out immense quantities and shipping it to LaSalle."[1]

After having extracted a large amount of lead and zinc ore, the latter of which has had a commercial value since about 1860, Mr. Mars-

[1] A History of JoDaviess County, p. 842, 1878.

den sold the mine in 1877 to the Illinois Zinc Company, of Peru, for $20,000. This company installed about $15,000 worth of machinery and operated the mine from 1877 to 1883. The old reports show an average output of 325 tons of zinc ore per month and almost as large an output of lead ore. In 1877 the ore averaged 45 per cent zinc, was worth $16 a ton, and was shipped to the company's factory at Peru, Ill. At this time 80 men were employed, raising 120 tons of ore per week. Later the number of employees ran as high as 125 men and boys, so that in 1881 the mine is reported to have produced an average of about a car of ore a day. In 1883, when zinc ore fell in price from $16 to $13 a ton, the mine was closed. When a new mill was erected in 1903,
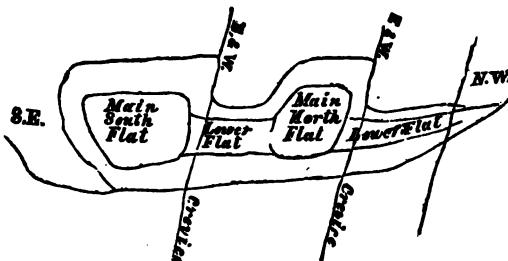
FIG. 7.   Ground plan of Marsden mine.   (After Chamberlin.)

an attempt was made to reopen the mine, but it was not running again until 1907. The mine was then operated by the Marsden-Black Jack Mining Company until the spring of 1908, when it was again closed because of another drop in the price of zinc ore. The following description of the mine as it existed in the early 80's is given by Chamberlin :[2]

From the surface, there descend two or more vertical crevices, which trend north 45° west. These carry some lead ore in the usual forms of a crevice deposit. At one point a considerable chimney was observed. At depths varying from thirty to eighty feet below the surface, according to position on its slope, these crevices encounter the two main upper flats. From all sides of these, the sheet pitches down. On the sides parallel to the vertical crevices, the pitches descend below the limits of present mining, and correspond to the similar declivities of the mines heretofore described. But along the axis of the lode, between the two main flats, the pitches descend about thirty-five feet and form a lower connecting flat, lying between the two main ones, as seen in the longitudinal profile. At the northwestern extremity, the sheet drops down into an undulating flat, while at the opposite extremity it pitches down to the bottom of the present mining. What may yet develop to the northwest remains to be seen.

At the points where the main flats break down—which are identical with the insets in the outline of the ground plan— the lode is traversed by east and west fissures to which the de-

FIG. 8.   Longitudinal section of Marsden lode.   (After Chamberlin.)

[2] Chamberlin, T. C., Geology of Wis., vol IV, pp. 748–480, 1873–79.

A. Marsden-Black Jack mine.

B. Northwestern mine.
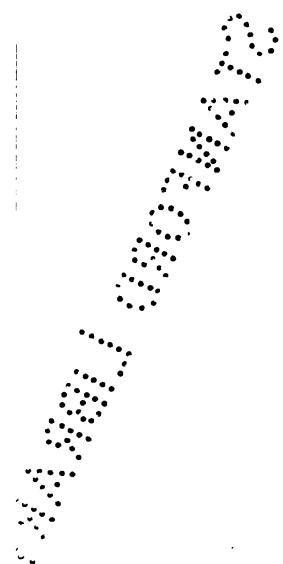
pression and contraction of the sheet has been assigned. It should not be understood, however, that there is any displacement of the strata. The main upper flats have a width of about seventy-five feet and a length of about one hundred feet. The pitches are mined to a vertical depth of sixty feet and are separated at their bases from seventy-five to two hundred feet, according as they belong to the wider or narrower parts of the mine. The
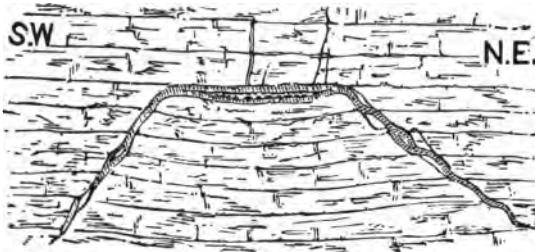
FIG. 9.   Transverse section of Marsden lode.   (After Chamberlin.)

character of the pitches is essentially similar to those described above, save that the walls are sometimes more separated, leaving a cavernous space between the ore sheets on either side, as illustrated by figure 10. Similar caves on the flats occur, attaining, in one case, eighteen feet in width, seventy-five feet in length, and from eighteen to twenty-four inches in height. Next the walls there is usually a thin coating of iron sulphide (pyrite or marcasite) on which is laid a sheet of blende to which the cubes of galena are attached, the whole, usually, overspread beautifully with pyrite, to which are sometimes attached calcite crystals, sometimes again overlaid with pyrite, the whole subject to interesting variations of form and succession.
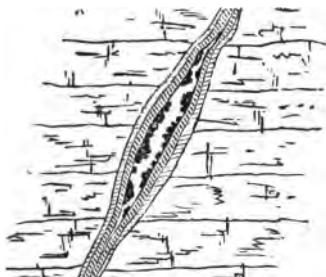
FIG. 10.   Section of cavernous opening on the pitch of Marsden mine.   Order of deposit, (1) pyrite, (2) blende, (3) galena.   (After Chamberlin.)

It is from such geodic caves, particularly those occurring on the flats, that the beautiful specimens, for which this mine is renowned, are derived.

Both stalactites and stalagmites of the ores are found in them, not only those of a single mineral, as pyrite or calcite, but composite accretions. One form consists of an irregular recticulated core of galena, surrounded by from one to three inches of blende, in radiant crystallization, coated on the exterior with pyrite, sparsely studded with small modified crystals of galena. In other cases the core contains calcite as well as galena.

These stalactites sometimes attain a diameter of six inches, and a length as great as the height of the cavern will permit, in fact, they sometimes form columns stretching entirely across the opening. Stalagmites, *bearing galena on their summits*, are said to have been found here.

On the west pitch, for a horizontal distance of about seventy-five feet, iron pyrites in thick botryoidal aggregations has almost entirely replaced the more valuable ores.

The beds of the country rock are nearly horizontal. When there is any dip, it is usually toward the center line of the range. At one point on the upper flat the beds dip slightly to the east. Near the upper flats, the rock is quite brecciated and the ores are distributed through the cracks and small cavities. Some features of the fragmentary structure seem due to original deposition, while others are clearly referable to fracture subsequent to solidification. This may be held as proven by the fact that nodules of

chert are fractured and the crevices filled with sulphides. The evidences of crushing and fission are most marked near where the pitches join the upper flats and near the vertical crevices. A shaly layer occurs about twelve feet beneath the upper flat, which is quite extensively impregnated with minute metallic crystallizations.

As evidence of recent changes, stalactites of calcite and limonite, an inch or more in length, were seen, which have formed since the space in which they occur was mined out. The waters of the mine are highly mineralized and make abundant red oxide deposits.

Mr. M. M. Gill gives the following statistics concerning the production of this mine from July 1 to November 1, 1907:

Production of Marsden-Black Jack Mine, July-Nov. 1907

Months	Hours mill run	Zinc concentrates (pounds)	Production per hour (pounds)	Lead made (pounds)	Lead per hour (pounds)
July....................................	217	998,400	4,600	60,000	276
August..................................	290	777,000	2,680	69,000	240
September...............................	352	952,000	2,700	165,000	470
October.................................	365	860,000	2,360	157,000	430
November................................	156	319,000	2,050	48,000	301
Total................................	1,380	3,906,400	2,830	499,000	361

The machinery and buildings have been kept in good condition and the mine has just (March, 1911) been pumped out and examined.

NORTHWESTERN MINE

The Northwestern mine (Pl. XIV, *B*) is located near the center of the N. ½ SW. ¼ sec. 22, T. 29 N., R. 1 E., less than one-half mile south of the State line and three-quarters of a mile from the railroad at Day's Siding. The first shaft was sunk in the fall and spring of 1904. It was 92 feet deep and penetrated the upper portion of the Platteville formation. Levels were run east and west for a total distance of 200 feet, the excavation of which was confined largely to a 15-foot layer of thinly bedded, fine-grained limestone with thin oil partings, such as characterize the base of the Galena dolomite. Below this occurs an 18-inch bed of clay, doubtless the clay bed which marks the boundary between the Platteville and Galena formations, as it is underlain by thin glass-rock beds.

In 1907 this shaft was abandoned and a new one was sunk farther to the east. The new shaft is 121 feet deep, and the main workings are just on top of the clay bed at the shaft. The ground has been opened up for about 200 feet east, 375 feet west, and 125 feet south. The ore occurs in thin sheets filling irregular fractures, in places thickening abruptly and in others thinning out as quickly. One 8-inch sheet of lead ore is reported to have been encountered. At one point

the main stope shows an opening about 20 feet high and 40 feet wide which is said to outline the ore body at that place. In the old shaft a series of northward pitching crevices were encountered but these have not been found in the new workings.

The ore consists in the main of blende mixed with considerable galena, the amount of iron sulphide being generally low. Intersecting crevices tend to increase the amount of lead ore. The mine is situated upon an oil-rock slope, where the clay bed shows a decided pitch to the southeast. Some good specimens of lead carbonate, cerusite, in small crystals one-eighth to one-quarter inch in size, coating cubes of galena were obtained here. The mine has lately been purchased by a new company and is now in active operation.

<div align="center">HOOSIER MINE</div>

The Hoosier mine is situated in the SE. ¼ SW. ¼ sec. 36, T. 29 N., R. 1 W. The present company began drilling about July 1, 1908, and sank the shaft in 1909. The shaft is located about 20 feet below the base of the Maquoketa shale and is 115 feet deep. A drill hole in the shaft shows the oil-rock at a depth of 240 feet from the surface. The shaft was sunk on an east and west crevice which carried galena near the surface. At a depth of 80 feet the "pipe clay opening" was encountered and two cars of hand-cobbed ore were extracted in sinking the shaft through this deposit. The opening is about 20 feet wide and 25 feet high, and rests upon a 1-inch layer of so-called pipe clay. This opening was filled to about 2 or 3 feet of the top with loose dolomite boulders heavily coated with blende, loose sheets of ore, which had apparently fallen from the walls, and sticky, dark organic mud, apparently washed in from the surface. Many of the irregular boulders seemed to be completely encased by the ore, showing that deposition has taken place in part since the fall of this material from the roof. At the time this mine was visited, drifts had been run for 380 feet with no apparent change in the character of the opening or of the ore.

A heavy flow of water is encountered from the Platteville formation through drill holes which have penetrated the oil-rock. The beds dip rather steeply to the west, in which direction the ore body soon passes from the confines of this property.

This mine shows remarkably well the character of the "openings" in which so much lead ore was found in the early days, but differs from those "openings" in containing practically no galena. The wall rock, except for the inner few inches, is hard and shows but slight traces of mineralization above and on the sides of the ore body. The rock below the ore body, however, is rather heavily impregnated with iron sulphide

and zinc blende, and about 10 feet of this is being worked in connection with the high grade ore in the opening. The mine is now apparently worked out and has been abandoned.

The Royal Princess mine (Pl. XV) is situated in the E. ½ sec. 27, T. 27 N., R. 1 E., upon an east and west crevice at about the center of a great series of such crevices known as the "California diggings" (Pl. XI), which extend along the Mississippi for a mile and a half and vary from 25 feet to 200 feet apart, all more or less mineralized. In many places the lead ore extended to the surface, hence the name "California diggings." Mining was carried on here largely between the years 1863 and 1875.

Inasmuch as nearly all the ore was taken from the "dry" in these diggings, it was thought that by the installation of pumps and the use of modern machinery, a valuable ore body might be opened up. Bain's[a] description is as follows:

The Royal Mining Company located three shafts on an east-west crevice about halfway up the slope of the ravine which parallels the vein. No. 1, the shallowest, was not visited. No. 2 starts in the Maquoketa shale and was sunk through 8 feet of that and then 147 feet of galena. There are two drifts from this shaft; the main drift at 105 feet, corresponding to a horizon slightly above the flint beds, extends eastward under No. 3 shaft. For a distance of 600 feet along this drift more or less galena and blende were won by both overhead and underhand stoping. The most interesting portion of this drift is immediately under the No. 3 shaft which was being sunk at the time the mine was visited. At this point the drift was 6 to 8 feet wide and to the east opened out into a large cave similar in all respects to those caves in which in early days the large finds of galena were made. This cave was full of water when first encountered, but at the time of visit the level had been somewhat reduced by pumping. At the east end it is about 12 feet wide and equally high. It narrows above to a mere crevice. Below, it was filled with loose rock, sand, and chunks of ore. On the walls were patches of a thin coating of iron sulphide, over which both blende and galena had formed as a crust and in the form of irregular crystal aggregates resembling nothing so much as toadstools. These were commonly 3 to 6 inches in diameter, and projected 2 to 4 inches from the wall. They seem to represent the free growth of crystals in a saturated solution. Many individual crystals of galena were of considerable size, as much as 2½ inches being measured on an edge. Apparently, after their formation, the conditions of the solution changed, since many of the galena crystals showed faces hollowed out to a true cup form as if by solution, and such surfaces were coated with a white material, doubtless lead carbonate. There was also a small development of zinc carbonate by alteration from the blende, and a very general oxidation of iron in the rock, as shown by the red color on the walls and the sand.

The significance of these facts lies in the circumstance that this whole cave and its contents underlie nearly the entire thickness of the Maquoketa shale, as was shown in the section of No. 3 shaft then being sunk, following a drill hole, to facilitate the excavation of the ore. In the shale there was no sign of either crevice or ore, but in the dolomite overlying the cave a small crevice showing a very little blende and galena was found. These

[a] Bain, H. F., Zinc and Lead Deposits of the Upper Mississippi Valley, U. S. Geol. Survey Bull. 294, pp. 78-79, 1906.

Royal Princess mine.

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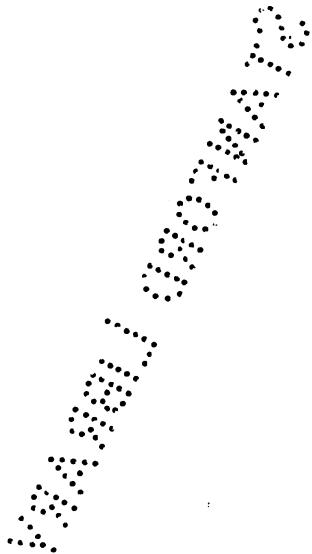
relations make it clear that under favorable circumstances, large and important bodies may be found under even a very thick cover of the impervious shale, and also that under present conditions surface oxidizing waters occur in quantity in the same situation. * * *

Below the main drift a second was seen, 147 feet below the top of the Galena dolomite. This drift, after being driven to the east 100 feet in a bar, was when visited headed in soft ground underlying one of the underhand slopes of the main drift. From the behavior of the water it was inferred that there was a connection between the two. No flats or pitches had been encountered, though the lower level was at a horizon at which they occasionally occur, and a diamond-drill hole was later put down in the bottom of the drift in search of them.

Since the publications of the above description, the adit of this mine has been extended so that its total length from the mouth of the tunnel to the face is about 2,350 feet. Bain has called attention to the fact that this ore body extends under the Maquoketa shale. It should be borne in mind, however, that the formation dips to the east and that the ore follows it downward. Also that at a distance of 2,975 feet from the mouth of the tunnel a sink occurs at the intersection of the crevice carrying the ore, and one striking about N. 26° east, a condition which affords ample connection with the surface. The intersections of the latter crevice with the other east-west crevices are usually marked by pronounced sink holes so that the line of the quartering crevice can be readily followed on the surface. These sink holes are located in the Maquoketa shale and there can be but little question as to the connection of these holes and the ore-bearing crevices.

PARAGON MINE

The Paragon mine is in sec. 23, T. 29 N., R. 1 E., on the old Captain Gear range. It is said that the smelter returns from this mine show that 27,000,000 pounds of lead ore was taken from above the water level. This is one of the first ranges worked in the district, one of the leases dating back to October 15, 1840. The old Waterman range lies just to the north.

The ore was found mainly in east and west crevices, although some of those running north and south carried ore. The intersections of the two series were exceptionally well mineralized.

This property is now leased by the Northwestern Mining Company, and three shafts have been sunk to depths of 130, 110, and 110 feet respectively. The bottoms of these are from 90 to 125 feet above the oil-rock. Lead and zinc ore is reported from all of the shafts, but especially from the first where it was found in flats.

The equipment of the mine consists of a shafthouse with bins sufficient to hold seven cars of coal, a boiler and engine, a Rand Imperial drill compresser, and a 100 h.p. friction hoist. The mine is still in the prospective stage and was not in operation at the time it was visited.

TEN STRIKE AND MERRY WIDOW MINES

The Ten Strike and Merry Widow mines, also the White Star, a prospect, are operated by the Ten Strike Consolidated Mining Company. All these mines lie near the center of the east edge of sec. 22, T. 28 N., R. 1. W. The two mines are adjacent and are located upon the same crevice, which strikes about N. 75° E., the Ten Strike being the farther east. A crevice opening containing lead ore was encountered at a depth of 65 feet in the east shaft. Two pitches containing lead and zinc ore branch from this opening and extend to a depth of at least 50 feet, the south pitch being the stronger. Oil-rock is reported to lie at a depth of 240 feet below the collar of the Ten Strike pump shaft. The Ten Strike mine is equipped with a 30-ton mill, and the Merry Widow mine with a 100-ton mill.

DRILL HOLE MINE

The Drill Hole mine is located in the NW. ¼ NE. ¼ sec. 9, T. 28 N., R. 1 E. The collar of the shaft is at an elevation of 844 feet above sea level and the shaft is 237 feet deep. The first 12 feet are said to have been slate-colored clay, doubtless the lower beds of the Maquoketa shale. The ore consists of galena with only a small amount of blende. It was found in a north and south crevice and in flat openings. It is claimed that over 200,000 pounds of ore have been extracted from the mine. The bottom of the shaft is below the flints and had just reached permanent water level.

FEDERAL MINE

At the time the field work for this report was being carried on this mine was not in operation and was known as the Illinois mine. In the spring of 1912 the mine was re-opened under the name of the Federal mine, and has been a regular producer during the past summer. The mine is located upon a range which strikes about N. 75° W. The ore is said to be of the form known as "sprangled jack" and to occur along a southward pitching crevice.

SHEBOYGAN MINE

The Sheboygan mine is in the NE. ¼ NE. ¼ sec. 10, T. 28 N., R. 1 E. The contract for the preliminary drilling on this land stipulated an increased rate of payment if good cuttings were obtained. It was concluded from the logs of the holes as furnished by the drillman that the showing was sufficient to warrant the erection of a plant and the sinking of a shaft. A shaft was sunk on one of the drill holes and

is said to have failed entirely to verify the presence of ore as reported in the drill record. This shows clearly the trouble that may result from having the drillman financially interested in the cuttings he obtains. The mine was never operated.

OTHER MINES

Among the less important mines in the Galena district, which are either inactive or have not been sufficiently developed for description may be mentioned the following: The Pilot Knob, Twin Jack, Great Western, and Betsy mines.

ELIZABETH DISTRICT[4]

WISHON MINE

The Wishon mine is situated in the SE.¼ NE. ¼ sec. 14, T. 27 N., R. 2 E. It is one of the oldest mines in the district, having been a producer as far back as 1865. But little work was done between the years 1875 and 1902 because of the lack of machinery with which to control the water. In 1902 the mine was reopened, new machinery installed, and a new shaft sunk to a depth of 150 feet; and in 1905 a 100-ton concentrating mill was added.

The main ore body lies in an east-west crevice whose course can be traced for a considerable distance on the surface by the dumps about old shafts. The ore was found both above, and in, the flint beds, extending down into the water. The ground is open, and in places well-defined pitches run down into the flints to the north and south. Both the mineralized and waste ground have been removed from between the pitches leaving great open drifts, some of which are 150 feet wide and 50 feet high.

SKENE MINE

Although situated in the SW. ¼ of sec. 25, T. 27 N., R. 2 E., just outside the area mapped in this report, the Skene mine, nevertheless, belongs to this group and so is included here. It was discovered by Chas. Ashmore in 1901, and operated by George Skene up to 1902, and by the Elizabeth Mining & Milling Company from 1902 to 1907, when it was shut down, apparently because of the fall in the price of lead and the high cost of mining. It has since been dismantled. The mine is said to have produced 4,000,000 pounds of lead ore.

The mine is located upon an "east and west" (N. 83° E.) crevice which at a depth of 96 feet branches into two pitches, the north one having a horseshoe shape, so characteristic of the Wisconsin field. Most

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[4] Cox, G. H., Elizabeth sheet of the lead and zinc district of norhern Illinois; Ill. State Geol. Survey, Bull. No. 16, pp. 32-34.

of the ore mined came from the south pitch, which has been opened up for over a thousand feet. It was associated with but a small amount of zinc and iron sulphides, the latter occurring both in layers on the walls of the openings and in distinct crystals. The north pitch has been prospected by cross-cuts and by drilling, which are said to show an increased amount of zinc blende. The core ground, between the two pitches, is more or less mineralized by small stringers of galena in the form of verticals and flats.

The mine is below permanent water-level but still within the oxidized zone. There was no apparent increase in the amount of zinc blende or any trace of zinc carbonate at or just below the level of permanent ground water. Drill records show the property to be underlain by the oil-rock which separates the Galena dolomite from the Platteville limestone, and which bears so important a relation to the lead and zinc deposits of the upper Mississippi Valley.

ILLINOIS MINE

This property is situated in the northeast corner of the SE. ¼ SE. ¼ sec. 23, T. 27 N., R. 2 E., on the main highway about half a mile from the Chicago & Great Western Railroad. It is on the old Richards range which was one of the heaviest producers of lead in the "dry" in the district, having yielded ore to the value of $210,000. It consists of a series of "east-wests," cut by "north-souths" and quartering. Ninety feet is said to be the maximum depth to which the mine was worked until 1906, when two shafts were sunk,—a hoisting shaft to a depth of 110 feet, and a pump shaft to 130 feet. A plant consisting of pump, hoist, and air compressor was installed and a drift was cut 150 feet to the south, following a thin sheet of galena.

KANSAS MINE

The Kansas mine is located on the SW. ¼ sec. 24, T. 27 N., R. 2 E. In 1906 two shafts were sunk on the old Van Meter range to depths of 127 and 200 feet, and were connected underground. In January, 1906, the company acquired the Riverside mine, located on the same quarter section but on the Pough range. Two shafts had been sunk by this company, the deepest being 160 feet. This mine produced some lead ore in 1909 but is closed at the present time.

BILL BURNS LEVEL.

It is estimated that about 1,000,000 pounds of lead ore was taken from the Bill Burns level, which is located in the NE. cor. NW. ¼

NE. ¼ sec. 19, T. 27 N., R 2 E.   The ore was found at the surface
in a north-south crevice and was followed down about 25 feet where the ·
ground became more open.   The ore was present in irregular openings
such as small pockets, fractures, and bedding planes, especially at the
crossing of two fractures.   At this level the ore body spread out in an
irregular flat, about 6 feet high and 80 feet in diameter.   Later, the
tunnel was lengthened to about 400 feet, and revealed small amounts
of lead in crevices, pockets, and along bedding planes throughout its
entire length.

The galena was found near the top of the flints just above the
present permanent water level.   The bottom of the tunnel is about five
feet above the level of the river.

EMPIRE MINE .

The Empire mine is located in the center of the NE. ¼, sec. 3,
T. 26 N., R. 2 E. on the Steel range.   It is equipped with boiler, pumps,
and hoist, and has two shafts, sunk to a depth of 50 feet.   A cross-cut
extends 60 feet to the north and is said to intersect five large east-west
crevices all of which are mineralized.   The mine is still in a prospective
stage, and was not entered by the writer.

ELIZABETH MINING AND DEVELOPMENT COMPANY

This property lies in the SE. cor. SW. ¼ sec. 24, T. 27 N., R. 2
E. on the Scott range near the town of Elizabeth.   The plant con-
sists of a boiler and hoist, and the development work includes a shaft 150
feet deep, and a small amount of drifting.   Mr. Barnett states that 30,000
pounds of lead ore have been taken out.   In December, 1909, the com-
pany was down 46 feet with a new shaft on the SW. cor. SW. ¼ sec.
24, where a drill hole showed lead values.

HAGGERTY MINING AND DEVELOPMENT COMPANY

The Haggerty mine is located in the SE. ¼ SE. ¼ sec. 14, on the
old Log Chain range, and is owned and operated on a small scale by
Geo. R. McLean.   It is equipped with boiler, hoist, and pump, and has
one shaft down 47 feet.

OTHER MINES

Besides the preceding mines there are numerous others, of which
some have been producers and others have not.   All of these look alike at
present, for machinery and equipment have been removed.   There is

nothing to reveal the amount of excavation except the dump piles, and nobody to tell of the production except one or two old miners who do not remember, or never knew, the amounts produced. Among these properties may be listed the Apple River mine, just north of this area; the Queen mine, just north of Elizabeth; the Old Haggerty mine, and several others. The Old mine located on the Old range at Marsville should also be mentioned.

Both slopes of Apple River are so completely covered with testpits that it is impossible to tell whether particular prospects went to bed rock only, or found a crevice; or whether ore was or was not extracted. A large amount of ore was obtained from these slopes, as well as farther back from the river, with no machinery except a windlass and bucket. The amount of ore extracted in this manner can be approximated only by taking the total production of the district and subtracting from this the output of the principal mines.

CHAPTER V—GENESIS OF THE ORES

REVIEW BY AUTHORS

D. D. OWEN

Like others of his time Owen believed that ores in general were derived from igneous rocks; that in the Wisconsin district such rocks had been intruded after the deposition of the sediments which now contain the ores; and that the ore-bearing solutions and gases given off by these rocks escaped upward along faults and fissures and resulted in the deposition of the ores in the formations above. His general ideas can be obtained from the following abstract from his report.[1]

By reference to my former report in 1839, it will be seen that it was considered a remarkable circumstance that in a mining district so rich as that south of the Wisconsin River no basalt, greenstone, porphyry, or other intrusive or crystalline rocks had, up to the time of the survey of 1839, been observed there, since these are in general found in place in the vicinity of productive mining districts. But I then expressed my belief, based upon the abundance of metallic lodes in that lead region and upon the irregularities of the dip of the strata in some localities, that granite and trappean rocks could not be far off.

There can be but little doubt that the whole mining region of the Mineral Point and Dubuque districts of Wisconsin and Iowa is based upon a syenitic or granitic platform, which would, in all probability, be reached by penetrating to the depth of from 2,000 to 4,000 feet.

While later developments have confirmed the presence of crystalline rocks below within the depths postulated by Owen, they have failed to show the presence of faults and deep fractures and of any igneous rocks younger in age than the ore-bearing formations. In fact the evidence all goes to prove that the igneous rocks are very much the older. It has also been shown that between the igneous rocks and the ore-bearing strata there are a number of clay bands which would make the ascension of ore baring solutions and gases very difficult if not impossible.

J. C. PERCIVAL

The first real study of the ores was undertaken by Percival[2] and Whitney.[3] Both were practical mining men and interested in mining operations, so that their conclusions were based upon conditions as they saw them at first hand. It is singular however that two contemporaries

[1] Owen, D. D., Geology of Wisconsin, vol. 4, p. 77, 1882.
[2] Percival, J. C., Wis. Geol. Survey, Ann. Rept., pp. 7–101, 1855.
[3] Whitney, J. D., Iowa Geol. Survey, vol. I, pt. 1, pp. 422–471, 1858.

having much the same experience, and each having first studied the problem from a practical standpoint and later from a theoretical one in the employment of the state of Wisconsin (Whitney also prepared reports for the states of Iowa and Illinois), should reach entirely different conclusions. Percival's work was, however, left unfinished by his early death.

Percival agreed with Owen in the belief that the ores were derived from below. Apparently his chief reason for so thinking was the occurrence of galena in considerable traces in the Prairie du Chien dolomite north of the Wisconsin River. He believed that workable deposits would be found in this formation.

> I have thus been able to trace the mineral in a series of crevices and openings from the summit of the Upper Magnesian (Galena dolomite) to the depth of 60 to 70 feet in the lower magnesian (Prairie du Chien dolomite), and have found all the beds of limestone good mineral-bearing rocks, each with one or more openings, besides vertical or pitching sheets or veins. The small depth to which mining has been extended does not allow one to trace the mineral through the whole of the extent downward in any one instance, but wherever circumstances permit of examination, the order of succession in the openings is found to be regular, and in multiplied instances vertical crevices and veins have been found passing down from one opening to another. It is then probable that the series is generally continued through the whole downward extent indicated, subject only to such interruptions as are more less common in all veins.[4]

> The opinion expressed in my former report that the mineral was derived from beneath, is strengthened not only by the general results of my observations in the diggings, but by the appearance of disturbance in the strata, particularly along the line of the great body of mineral traversing the middle of the district, and by the relation in the bearing of that body to the extensive ranges of primary and metamorphic rocks towards the northeast, indicating that the mineral may have arisen from a mass of such rocks beneath the secondary strata.[5]

J. D. WHITNEY

Whitney showed his genius by going beyond the general views of his day and advancing a sedimentary origin for the ores, upon which practically all the later theories, including those in vogue today, are based. He believed that for some unknown reason the sea of each geologic age was richer in metallic substances than any later sea; that the ores were precipitated from the sea by the reducing action of hydrocarbons, produced during the decay of the bodies of marine animals whose shells form the limestone, and of the weeds which grew on the sea bottom. The metallic compounds were thus scattered throughout the formation in very finely divided particles, to be later concentrated by ordinary meteoric waters. He recognized the importance of secondary concentration in the localization of the ore bodies, but also appealed to

[4] *Loc. cit.*, p. 68.
[5] Wis. Geol. Survey, Ann. Rept., p. 63, 1856.

local enrichment of organic matter to account for this. Chamberlin[6] has raised the following objections to this theory:

(1) The metallic deposits would correspond to the introduction and distribution of life.

(2) The ores would appear in the strata where life first appeared.

(3) The ores would be abundant or sparse, according to the luxuriance of life.

(4) The ores would continue prevalent in the life-bearing beds till the oceanic supply was exhausted, when they would cease.

None of these conditions are fulfilled by the occurrence of the ore bodies.

The points of this theory which are of essential interest to us at the present time are (1) the derivation of the ores by the leaching of the pre-Cambrian crystalline rocks to the northeast, (2) the transportation of the dissolved material to the Paleozoic sea by streams, (3) the precipitation of the ores from the sea by the reducing action of hydrocarbons, (4) their deposition with the Paleozoic sediments, (5) and their concentration by meteoric waters.

T. C. CHAMBERLIN

Chamberlin's report[7] for the state of Wisconsin contains the most complete description of these deposits yet published. Although he does not entirely agree with Whitney in his explanation of the ores, he nevertheless retains the main points of his theory. For the precipitation of the ores from the sea he appeals to the reducing action of hydrocarbons resulting from the decay of organic matter, but organic matter of a vegetable nature rather than that of animal. The source of these decomposition products is found largely in the so-called oil-rock at the base of the Galena formation. He shows how the oil-rock may have resulted from vegetable accumulations in a sargasso sea, and how the sea may have been locally enriched in lead and zinc in the same manner. His computations indicate that the percentage of lead and zinc in the Galena formation necessary to account for the concentration of the richest known ore bodies is very small—"one fourteen hundredth of one per cent." He recognized a relation between the ore deposits and the oil-rock basins and explained it by assuming that the depressions of the present oil-rock basins existed on the bottom of the Galena sea, and that the oil-rock, and therefore the ores, accumulated to a greater thickness in these basins than elsewhere.

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[6] Chamberlin, T. C., Geology of Wisconsin, vol. IV, p. 372, 1873–79.
[7] Chamberlin, T. C., The ore deposits of southwestern Wisconsin: Geology of Wisconsin, vol. IV pp. 365–371, 1882.

According to this theory the ore existed in the Galena formation as very fine particles in a disseminated condition. It was taken into solution by ordinary meteoric water, assisted largely by humic acids, as it percolated down through the small pores of the limestone, and was carried laterally to openings, and there precipitated by organic matter washed from the surface.

Two possible explanations are offered to explain the vertical distribution of the ores:

(1) The lead was originally precipitated in the upper portion of the Galena formation and the zinc and iron in its lower portion and each has been concentrated within its particular horizon.

(2) The vertical distribution represents the order of deposition from ascending solutions.

W. P. BLAKE

Following Chamberlin came Blake and Jenney, who, although contemporaries, differed in most of their beliefs except that faults existed in the district. Blake accepted the occurrence of faults,[8] but believed with Whitney that the ores were derived from the surrounding contemporaneous sediments and that their localization was due to local abundance of organic matter; and with Chamberlin that the organic matter was furnished by the oil-rock and not by the decaying bodies of marine organisms. In fact, his main contribution was not in suggesting something new, but in calling attention to the significance of the oil-rock which had been previously referred to by Chamberlin. Blake also called attention to the close coincidence of the boundaries of the lead and zinc district and the Driftless Area, but offered no explanation for the phenomenon.

W. P. JENNEY

Jenney was a man of experience in lead and zinc work, for he had spent a considerable time in the Missouri field as well as in that of the upper Mississippi. His main work was, however, in the Ozark region. Jenney followed Percival in assigning an igneous origin to the ores which he thought had ascended through faults and fissures that controlled their lateral distribution. His ideas are expressed in the following quotations from his report:[9]

The result of this investigation of the deposits of lead and zinc in the Mississippi Valley has made it possible to announce the general law that all workable deposits of ore occur in direct association with faulting fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore.

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[8] Bull. Geol. Soc. Am., vol. 5, pp. 25–32, 1894; Trans. Am. Inst. Min. Eng., vol. 22, pp. 558–568, 621–635, 1893.

[9] Paper read before a meeting of the American Institute of Mining Engineers in 1893, p. 14.

In conclusion it may be said of the fissures, which occur in direct association with the deposits of lead and zinc ores in the Ozark and Wisconsin uplifts, that they are not the result of local causes, and are not confined to a narrow vertical range, or to rocks of a similar lithological character, but, on the contrary, that these fissures are the result of forces connected with wide spread dynamic disturbances, affecting the North American continent, and that the fissures are fault planes of indefinite vertical extent, traversing all the geological formations from the crystalline rocks to the "Coal Measures."

ARTHUR WINSLOW

Winslow made a close study of the lead and zinc ores of Missouri, especially those of the Ozark region, and reached the conclusion[10] that the ores were derived from above by the decomposition and erosion of superimposed strata and were concentrated by descending meteoric waters. Buckley and Buehler[11] have recently come forward in support of this hypothesis as applied to the Missouri lead and zinc deposits. From the similarity in the occurrence of the ores in the two districts, Winslow concluded that the conditions were equally applicable to the upper Mississippi Valley district. He quoted a large number of analyses which proved the general presence of lead and zinc in the rocks of the Missouri district. The average of these analyses showed 0.00198 pounds of galena per cubic foot of limestone, or dolomite, and 0.0063 pounds of zinc blende.

It should be borne in mind that Winslow appealed to all the overlying formations and not to any one for the source of the ores. Apparently he did not have in mind the overlying Maquoketa shale inasmuch as none of this rock was analyzed for him.

A. G. LEONARD

From his work for the Iowa Geological Survey, Leonard concluded that the theory of origin and concentration of the zinc and lead ores of Wisconsin as outlined by Chamberlin "furnishes, on the whole, the most plausible explanation yet offered for the localization of the upper Mississippi deposits."[12] He calls attention to the seemingly impossible concentration of the ores from formations above, as advanced by Winslow, because of the thick and impervious Maquoketa shale which overlies the Galena dolomite.

SAMUEL CALVIN AND H. F. BAIN

In 1900 Calvin and Bain,[13] as a result of their work for the Iowa Geological Survey in the vicinity of Dubuque reached practically the

[10] Winslow, Arthur, Missouri Geol. Survey, vol. 7, pp. 477-487, 1894.
[11] Buckley, E. R. and Buehler, H. A., Missouri Bureau of Geology and Mines, vol. 4, 2d series, 1905.
[12] Leonard, A. G., Iowa Geol. Survey, vol. 6, p. 61, 1896.
[13] Bain, H. F., Geology of Dubuque County, Iowa Geol. Survey, vol. X, pp. 270-622, 1900.

same conclusions as previously outlined by Chamberlin. They made a series of analyses of limestones and dolomites after the manner of those made by Winslow to show the general presence of lead and zinc in disseminated form in the country rock.

C. R. VAN HISE

In 1901 Van Hise discussed[14] some of the principles controlling the deposition of ores and applied them to this district. He agreed with Whitney and Chamberlin in the primary origin of the ores, their precipitation from the sea, and their deposition with the Paleozoic sediments, but appeals to an artesian circulation to account for their concentration. The oxidizing water, he thought, enters the southward dipping strata where they are exposed at the surface to the north, passes downward and laterally through the small pores and along joints and bedding planes, dissolves the disseminated mineral of the formation, and finds an outlet to the south where the Maquoketa shale has been eroded. The points at which the shale was first eroded defines the position of the deposits of the first concentration. However, there may have been a number of secondary concentrations by downward moving water, and to this, appeal is made to account for the vertical distribution of the ores.

R. E. DAVIS

Davis[15] advanced the hypothesis that the ores were precipitated from the Ordovician sea by the hydrocarbon decomposition products of the oil-rock, and therefore the ores were originally contained within the oil-rock; that they were taken into solution by fatty acids from the oil-rock, carried upward, and precipitated in the openings of the formation above.

He agrees with Chamberlin in that the oil-rock is supposed to have been formed in a sargasso sea, and with Chamberlin and Blake in the precipitating power of the organic acids and gases given off by decomposing organic water. He shows that the ores are soluble in organic acids and that their precipitation from ascending solutions in these would be in the following order, starting at the bottom: marcasite, galena, sphalerite. He agrees with Bain in the explanation of the horizontal distribution of the ores and in the origin of the flats and pitches.

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[14] Van Hise, C. R., Trans. Am. Inst. Min. Eng., vol. 30, pp. 27–177, 1901.
[15] Davis, R. E., Thesis, University of Wisconsin, 1906. Unpublished.

H. F. BAIN

In 1906 Bain published his theory of origin[16] of the lead and zinc ores of this district. Although proposing practically nothing new, he has combined the better portions of the various theories and welded them into a single consistent one. He has followed Whitney in explaining the primary origin of the ores and Chamberlin in discussing the manner of their precipitation, but he surpasses both in the amount of detailed evidence cited to support his views. A more detailed account of this theory will be given in another place. (See pages 69-71.)

U. S. GRANT

In 1903,[17] 1905,[18] and 1906,[19] Grant prepared bulletins for Wisconsin Geological and Natural History Survey and the United States Geological Survey, in the first of which he discussed the origin of the ores in accordance with the ideas earlier presented by Van Hise. In 1907[20] he prepared a folio for the United States Geological Survey in which he briefly outlines the origin of the ores, giving the same theory as previously published by Bain in 1906. Bain and Grant worked together in the district and were closely associated, and, consequently, the theory for the origin of the ore deposits here accredited to Bain was in reality worked out by these two men in co-operation although Bain's paper was published first.

C. K. LEITH

Leith,[21] like Chamberlin, believes the ores to have been precipitated from the Ordovician sea by the organic compounds given off by the oil-rock, but does not think that the ore particles were all finely disseminated or uniformly distributed through the formation. He thus differs from all others, at least, so far as they have committed themselves, in believing that some, at least, of the ore deposits represent original concentrations by direct precipitation from the Galena sea.

SUMMARY OF THE GALENA-OIL-ROCK THEORY AS ADVANCED BY BAIN AND GRANT

For the original source of the zinc and lead we must doubtless look to the crystalline rocks of the Lake Superior region. It is from this region

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[16] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull 294, 1906.

[17] Lead and zinc deposits of southwestern Wisconsin: Wis. Geol. & Nat. Hist. Survey Bull. No. IX, p. 103, 1903.

[18] Zinc and lead deposits of southwestern Wisconsin: U. S. Geol. Survey, Bull. 260, pp. 304-310, 1905.

[19] Lead and zinc deposits of Wisconsin, with atlas: Wis. Geol. and Nat. Hist. Survey, Bull. XIV, p. 100, 1906.

[20] Grant, U. S. and Burchard, E. F., U. S. Geol. Survey Geol. Atlas, Lancaster and Mineral Point folio (No. 145), p. 14, 1907.

[21] Unpublished article.

that the lime, magnesia, and sand now found in the formations of the zinc and lead regions came. In Canada and northern Minnesota there are scattered deposits of the ores of these metals in the older formations, which were exposed to erosion in Platteville and Galena times. During these epochs the region was apparently base-leveled and the drainage from a wide area reached the bordering seas. Mechanical erosion was at a minimum and solution was active. Magnesium, lead and zinc have many chemical reactions in common, and it would seem inevitable that where one of these metals was transported in quantity from the land to the ocean, the others would follow, and that certain amounts would be deposited.[22]

According to this theory the Ordovician sea in which the Galena limestone was formed contained these metals in solution.

During the formation of the Galena limestone, the decomposition of the organic matter in the oil-rock below produced organic acids and gases which rose up through the then unconsolidated material into the sea and caused the precipitation of the lead, zinc, and iron compounds held in solution, so that minute particles of the sulphides of these metals were scattered throughout the beds of the Galena during the course of its formation. After the deposition of the Galena limestone and the overlying formations, the sea retreated, the area became dry land, and the overlying formations were eroded. Following the exposure of the Galena limestone as the result of this erosion, the disseminated ore particles were taken into solution by ordinary oxidizing water from the surface as it percolated through the limestone (which was probably undergoing dolomitization at this time), carried laterally to openings, and there deposited, where it may have since undergone one or more secondary concentrations.

In regard to the location of the district, Bain[23] states:

The present ore bodies are believed to have been formed mainly by the reduction of sulphates to sulphides as a result of the mingling of solutions and reactions between ore-bearing solutions and organic matter in the country rocks. To a subordinate degree the sulphurization of carbonates has probably taken place. It seems altogether likely that the original precipitation of the materials from the sea water occurred through the same reactions. If this be true, any original localization of the material may have been due to—

(a) Local abundance of the metals in solution.
(b) Local abundance of the organic reducing matter.
(c) Locally peculiar organic matter, leading to particular efficiency in producing decomposition.

Under "Local abundance of the metals in solution" attention is called to the fact that the lead and zinc minerals are unequally distributed in the crystalline rocks and hence the water entering the sea from streams draining the more richly mineralized portions of the region would be abnormally rich in the salts of these metals, which might result in the location of ore deposits near their mouths.

The only direct evidence favoring it is the fact that the structural basins in which the ores now lie are suggestive in shape of embayments at the mouths of streams or drowned river valleys. The presence within them and not generally elsewhere of considerable amounts of mechanical sedi-

[22] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294, p. 129, 1906.
[23] Idem, p. 133.

ment deposited during a general period of base leveling is furthermore suggestive of nearness to rivers.[24]

Under *local abundance of organic matter* is emphasized Chamberlin's statements that structural basins existed at the top of the Platteville limestone, that during the time in which the oil-rock was being formed these basins must have caught most of the organic matter deposited, and that the ores show a close relation to these basins.

Under *locally peculiar organic matter, leading to particular efficiency in producing deposition* is given a table showing the relative reducing powers of various elements and compounds of which CH_4 ranks second only to hydrogen. An analysis[25] of the oil-rock is given which shows it to be capable of giving off 57 volumes of gas which approximates CH_4 in composition.

Bain thus ascribes the localization of the ores to the peculiar composition and precipatating power of the oil-rock and its decomposition products. He accounts for the irregularities in the lateral distribution of the ores and their apparent relation to the oil-rock basins as being in a large part due to unequal original deposition because of the accumulation of the oil-rock in these basins.

DISCUSSION OF THEORIES

The direct igneous source of the ores as proposed by Owen, Percival, and Jenney is not tenable for the following reasons: (1) no general faulting or fissuring producing openings extending from one formation to another have been found in this district; (2) there are in general two or more clay beds below the ore deposits through which it would be practically impossible for the proposed ore-bearing solutions to pass; (3) igneous rocks are exposed nowhere in the district and the only ones known to be present are those of the basal complex more than a thousand feet below, and these are all very much older than the formations in which the ore is found; (4) ore in paying quantities has never been found in the Prairie du Chein dolomite, as should be expected from this theory of origin; and (5), the St. Peter sandstone, the Prairie du Chein dolomite, and the Potsdam sandstone are very porous formations, so that any ore-bearing solutions rising up through them would be so greatly diluted that they would be impotent for the formation of the ore deposits in the overlying formations.

So far no objections have been raised to the conclusion reached by Whitney that the ores were derived from the crystalline rocks constituting the land areas to the northeast and precipitated with the sediments from the sea by the reducing action of the organic matter. The state-

[24] *Loc. cit.*
[25] *Idem*, p. 26.

ment that the organic matter was derived from the decay of the fleshy parts of the marine animals of whose casts the Galena and Platteville limestones were formed, does not seem warranted unless it is assumed that the sea was exceptionally rich in zinc and lead compounds at this place and time, for many limestones are just as fossiliferous as those in this district, and yet they do not contain ore deposits.

Chamberlin, by attributing the reducing agent to vegetable decay and in particular to that contained in the oil-rock, has, at least, an agent which is confined to these formations and the general mining district. His postulation of a sargasso sea is of course theoretical. His attempt to explain the localization of the deposits in Missouri and other states by this same sea does not seem to be warranted, as these deposits occur in different formations, ranging in age from Cambrian to Carboniferous. His conception that the vertical distribution of the ores is due to their having been precipitated from the Ordovician sea at different times, the lead in the upper, and the zinc and iron in the lower portion of the Galena limestone, is apparently based upon the fact that lead ore is usually found above that of the zinc and iron. Whereas it is a fact that in a given section the galena usually lies above the sphalerite, the lead ore is characteristically near the surface and above the water table and the zinc ore at a lower level, below the water table, so that these deposits bear a relation to the land surface and the water table rather than to any horizon within the Galena dolomite.

In answer to Winslow's conclusion that the ores have been derived from the erosion of younger formations above, it seems to have been thought sufficient to call attention to the impervious character of the Maquoketa shale, which directly overlies the ore-bearing formation. Whereas the impervious character of this shale might prevent the ore from being derived from any formation above it, it would not prevent the ores from being derived from the shale itself, a fact which seems to have been entirely overlooked.

In the artesian theory of origin as proposed by Van Hise, the chemistry of the solution of the ores under oxidizing conditions, their later transportation through so long a distance by solutions which must become reducing and alkaline in nature, and their precipitation on encountering surface conditions, does not seem to agree with the most probable chemical reactions that have taken place in this district. Also, the ore deposits do not show any such relation as might be taken to indicate that they occur at the places where the shales were first eroded.

The possibility that some of the ore deposits were formed in their present condition by direct precipitation from the sea, as proposed by Leith, is thought by the author to be contrary to the field evidence. Such

a method of deposition would result in the formation of disseminated ore bodies, and such deposits are seldom found in this district.

In fact, it seems safe to say that about 95 per cent of the ore mined in this district comes from openings such as fractures or bedding planes more or less enlarged by solution. The Baxter mine near Cuba City, Wis., is usually cited as the typical disseminated deposit of the district. It was the writer's privilege to spend two days in a careful study of this mine. The ore was found to occur mostly in fractures and vugs lined with calcite. The ore stopped abruptly at the edges of the deposit. Small seams of zinc blende filling fractures in the cherts were common. In these cases the ore was clearly younger than the limestone. Crevices and soft decomposed dolomite extended from the ore to the surface, and afforded sufficient opportunity for the deposition of the ore from surface waters. In no mine which the writer has examined has there not been clear and ample connection, either by fractures or solution openings, between the deposit and the surface.

The theories of origin of the ores as advanced by Whitney, Chamberlin, Van Hise, and Davis who appeal to ascending or laterally moving solutions, and especially those of Chamberlin, Davis, and Leith who postulate the precipitation of the ores from the Ordovician sea by the organic matter of the oil-rock, are open to many of the objections which have been raised to the so-called "Galena-oil-rock theory" as advanced by Bain and Grant. Because of the detail in which this theory has been given and its general acceptance in the mining district, the objections to it are given in more detail.

OBJECTIONS TO THE GALENA-OIL-ROCK THEORY

It is not purposed, or possible at this time, to give all the arguments that might be raised against the Galena-oil-rock theory. During the four seasons that the author has spent in this district in the employment of the States of Illinois and Wisconsin, a number of points have been noticed that do not seem to be satisfactorily explained by the conditions postulated in the preceding theory. These are briefly outlined below:

1. It is impossible to prove that any lead and zinc compounds ever existed as original minerals in the Galena limestone of this region, and therefore, that this is an ample source of supply for the ore. A series of nine analyses is given by Bain[26] to show the general presence of lead and zinc in all limestones. Of these, all show the presence of small amounts of lead, and six show zinc in the fourth decimal place; but they have all been subjected to the action of surface waters, and it is impos-

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[26] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull 294, p. 130, 1906.

sible to say that all, or any part, of these metals has not been introduced from some formation above.

2. The Galena-oil-rock theory does not explain the presence of large crystals of galena ("cog mineral"), found in the "openings" in the Dubuque and Elizabeth districts. It cannot be supposed that water passing through the small pores of the limestone and dissolving the ore, as postulated by this theory, could be other than alkaline or neutral. Buckley and Buehler,[27] however, have shown that lead, zinc, and iron sulphides precipitated from neutral solutions are thrown down in an intimate mixture. Further, lead and zinc sulphides are thrown down from alkaline solutions when precipitated by the neutralization or dilution of their solutions, or by the action of hydrogen sulphide upon them. Hence the formation of pure crystals of galena by this theory would involve a primary concentration of mixed sulphides and a later segregation, either by the leaching out of the more soluble zinc and iron sulphides or by the solution of the whole and the reprecipitation of the galena by itself. The first process would result in a residual of porous, iron stained galena, instead of the well-crystallized lead sulphide so characteristic of these openings. Moreover, the occurrences of large amounts of this so-called "cog mineral" in the Dubuque and Elizabeth districts at practically the top of the Galena dolomite seems to preclude the second process; furthermore, such lead ore found lower in the formation, and known to be due to secondary concentration, always occurs in small crystals.

3. The general order of occurrence of the three principal sulphides of the district from the surface downward is galena, blende, and iron sulphide. As previously stated, the solutions which are supposed to circulate through the limestone and dissolve the minute particles or ore cannot be acid in nature, and hence the first concentration of the ores from such solutions would be an intimate mixture of them all, so that the Galena-oil-rock theory must appeal to secondary concentration to explain the vertical distribution of the ores.

4. Whereas the distribution of the oil-rock (Pl. IX) corresponds somewhat closely to the area of the upper Mississippi Valley district, and the thickest oil-rock is found in the general neighborhood of the best mining areas, as at Platteville and Hazen Green, Wis., the lateral distribution of the ores within the district does not correspond to the thickness of the oil-rock. Thus whole townships in the vicinity of Lancaster, Wis., are practically barren, but others near Highland, underlain by less thickness of oil-rock, are heavily mineralized. The thickness of the oil-rock in the vicinities of Fennimore and Dodgeville, Wis., is practically

[27] Buckley, E. R. and Buehler, H. A., Geology of the Granby district: Missouri Bureau of Geology and Mines, vol. IV, p. 107.

the same, yet but little ore has been found near Fennimore, whereas the Dodgeville area has been a large producer. Bain[28] has noted the weakness of this view in the following words: ·

"It has been separately pointed out that thick oil-rock has not been found away from the mines. Reasons have been given for believing that the reverse relation holds—namely, that ore deposits will not be found except in areas of thick oil-rock. Since this is easily recognized in drill cuttings, it becomes a valuable supplementary guide in prospecting. It is important to have more data on this point in order to test the matter thoroughly. It may be frankly stated that at present the suggestion is based largely upon theory.

5. The explanation offered for the occurrence of the ore deposits in the oil-rock basins is not satisfactory. Their occurrence in the basins has been explained by Bain as due to thicker oil-rock and hence greater original precipitation of the ores in these areas. However, the following facts should be noted: First, that, in some of the smaller folds at least, the oil-rock is likewise thicker on the crests of folds than on the limbs; second, that there are many areas without ore deposits which are underlain by greater thicknesses of oil-rock than are present within many of the basins which do carry deposits, and that there are many of these basins with thick oil-rock but no ore; and third, that the flats and pitches, and openings in general are more abundant in the oil-rock basins, and that the ore-bearing solutions must be controlled by these openings and the pitching, impervious oil-rock troughs. The relation between the oil-rock basins and the ore deposits is therefore probably structural and not genetic.

6. Lead and zinc ores are found outside the district underlain by the oil-rock. Such an occurrence is reported by Shaw[29] as follows:

Galena, or common lead ore, is and has been mined to some extent. There is an old crevice mine near the mouth of Yellow Creek, near Freeport, that has often engaged attention in years past, but no heavy amounts of mineral have ever been taken from it. From the quarries near Lena, "chunks" as large as the fist have been taken. In the township of Oneco, a company of Freeport men prospected to a considerable extent, and obtained several hundred pounds of mineral. Near Weitzel's mill some "prospecting" has been carried on. Along the banks of Yellow Creek some "float mineral" has been picked up, and in almost any of the quarries, small bits of ore may be detected.

Thus although ore was not found in any great quantity outside of the oil-rock areas, nevertheless, the conditions which caused the occurrence of the ores in the main oil-rock district were effective elsewhere. No trace of the oil-rock has been found at Freeport, or about Rockton, Orangeville, Buena Vista, and Sciota Mills to the northeast, north, and northwest of Freeport. Its nearest occurrence is 15 miles away, and it is not probable that at this distance it could have been effective in precipitating the ores.

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[28] Bain, H. F., Zinc and lead deposits of the upper Mississippi valley: U. S. Geol. Survey Bull. 294, p. 144, 1906.
[29] Shaw, James, Geological Survey of Illinois, vol. V, p. 72, 1873.

North Buena Vista, Iowa, marks the northwest limit of the oil-rock which is here represented by a few thin layers of shale, that emit a slight oil-rock odor but will not burn. Ore in paying quantities, however, has been mined west of Buena Vista, Turkey River, and Guttenburg, Iowa.

7. According to the Galena-oil-rock theory the location of this district was due to one of three things: (1) local abundance of the metals in the Ordovician sea, (2) local abundance of reducing matter (oil-rock), or (3) peculiar precipitating power of the reducing matter (oil-rock). If any, or all, of these conditions prevailed, we should expect that the presence of any other formation with an organic content equal to, and as strongly reducing as, that of the oil-rock, would cause precipitation of an amount of ore equal to that precipitated by the oil-rock. It will be shown later that there probably was another formation present which not only contained organic matter with a reducing power equal to that of the oil-rock, but a much greater quantity of it.

8. If the localization of the ores is the result of the precipitating power of the oil-rock acting in a sea of uniform or decreasing metallic content, this precipitation would have taken place most rapidly when the oil-rock was first formed and the gases evolved from it were most abundant and were free to escape readily. Precipitation would decrease rapidly with time and with the accumulation of the superimposed Galena limestone. Under these conditions the original disseminated ore particles would not be scattered uniformly throughout the Galena limestone, but would be most abundant at its base, and would decrease rapidly in amount with the distance from the oil-rock. No evidence of such a concentration has yet been found; in fact, all evidence seems to point to the opposite condition. Drill records have so far failed to show the general presence of ore deposits near the oil-rock in the southern portions of the field; on the contrary, the ores seem to bear a strong relation to the water table, rarely exceeding a depth of more than 100 feet below this level. The ore shows but little relation to the oil-rock unless the rock lies within this zone, and then, apparently, not because of any direct effect it exerts upon the ore itself, but rather because of the control it exerts upon the water circulation and the formation of the flats and pitches in which the ore was deposited.

9. The ore deposits occur generally in openings developed by solution along fractures. A large portion of the solution must have taken place before the deposition of the ores, since much of it occurs as coatings on the walls of the crevices. If the ores were derived from the wall rock, it seems reasonable to suppose that the seepage from the walls, and therefore the deposition of the ores, would be contemporaneous

with their solution and that the two processes would continue until the wall rock was depleted of its metals.

10. Most of the ore deposits occur in solution openings that are directly connected with the surface and which, without doubt, have been formed by the direct access of meteoric water. The presence of shells within the ore shows that, in places at least, solution of the dolomite has been contemporaneous with the deposition of the ores. But solutions which have passed through the small pores of the Galena dolomite for a considerable distance, as postulated by the Galena-oil-rock theory, would be saturated with lime carbonate, and incapable of further solution of the dolomite, so that they could neither have formed the openings in which the ore occurs nor have enlarged them.

11. The borders of the ore deposits are almost invariably marked by a decrease in the proportion of zinc and lead compounds present and a relative increase in the proportion of iron sulphide. Such conditions exist at the bottom and on the sides of the deposits but not at the top, indicating that the solutions were descending.

OUTLINE OF A PROPOSED HYPOTHESIS OF THE ORIGIN OF THE ORES

INTRODUCTORY STATEMENT

In outline the proposed hypothesis of the origin of the lead and zinc ores of this district follows Whitney, Chamberlin, Blake, Winslow, Calvin, Van Hise, Grant, Bain, and others, so far as it assumes that the ores existed originally as more or less finely disseminated particles in the pre-Cambrian igneous rocks which constituted the land areas somewhere to the northeast in Ordovician and pre-Ordovician times, and that the metallic compounds were leached out of these rocks by the ordinary process of weathering and were carried to the sea by the streams and there deposited with the sediments through the reducing action of organic matter.

Further than this the writer is not in agreement with any of the above-mentioned authors with the possible exception of Winslow, who believed the ores to have been deposited from descending solutions. It is thought that the ores were deposited from the Ordovician sea with the Maquoketa shale; that the precipitation of the ores was due to the reducing action of the organic matter contained in these shales; that with the erosion of the Maquoketa shale the ore particles were taken into solution, carried downward, and deposited in the openings in the Galena formation by ordinary meteoric waters, and that the ores have since undergone some secondary concentration.

ULTIMATE SOURCE OF THE ORES

In the ultimate source of the ores there is perfect accord with the conditions as expressed by Bain[30] in the following paragraph:

For the original source of the zinc and lead we must doubtless look to the crystalline rocks of the Lake Superior region. It is from this region that the lime, magnesia, and sand now found in the formations of the zinc and lead regions came. In Canada and northern Minnesota there are scattered deposits of the ores of these metals in the older formations, which were exposed to erosion in Platteville and Galena times. During these epochs the region was apparently base-leveled, and the drainage from a wide area reached the bordering seas. Mechanical erosion was at a minimum and solution was active. Magnesium, lead, and zinc have many chemical reactions in common, and it would seem inevitable that where one of these metals was transported in quantity from the land to the ocean, the others would follow, and that certain amounts would be deposited.

IMMEDIATE SOURCE OF THE ORES

INTRODUCTORY STATEMENT

Under this head it is proposed to show that of all the formations known to have been present in this district, the Maquoketa shale is the most favorable source of the ores.

THE PRECIPITATING AGENTS IN THE MAQUOKETA SHALE

The relation between the original organic and metallic contents of sedimentary formations.—The reducing power of organic compounds, especially those of organic acids and gases, and their strong precipitating action on certain metallic elements when in solution as sulphates or carbonates, is well known. All of the late writers have appealed to this to account for the precipitation of the lead and zinc ores of this district. It is also, I believe, a well recognized fact that, as a rule, those unaltered sedimentary formations which have the highest organic content also contain the largest amount of original metallic sulphides, as illustrated by the omnipresence of marcasite in coal and coal slates. Zinc blende itself is not of uncommon occurrence in such formations, as has been mentioned by Bain[31] and by Buckley and Buehler.[32]

If a series of analyses of some unaltered sedimentary formation were available, it might well be expected that those portions which contained the most organic matter would also contain a corresponding larger amount of original metallic sulphides. In other words, other things being equal, we might expect to find a rather close relation between the amounts of organic matter and metallic sulphides. Unfortunately such analyses are not available. Also, very few analyses are

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[30] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geological Survey Bull. 294, p. 129, 1906.
[31] *Idem*, p. 131.
[32] Buckley, E. R., and Buehler, H. A., Geology of the Granby Area: Missouri Bureau of Geology and Mines, vol. IV, 2d series, p. 81.

complete, especially in these particulars. The comparison of the analyses of similar rocks from different localities is always open to the objection that they may not have been formed under exactly the same conditions. The only method of making such comparison is to use the averages of large numbers of analyses on the assumption that these will show the general relations that exist between the organic matter and the metallic contents of average sedimentary rocks. Such a summary is given by Clark[33] from whose report the following figures are taken:

Partial analyses of sedimentary rocks

(Collected by C. K. Gilbert, assisted by G. W. Stose, of the U. S. Geol. Survey and analysed by Dr. H. N. Stickes.)

	A	B	C	D	E	F	G
Fe₂O₃..................	4.00	4.04	4.03	1.06	(1.39)	.54	.77
FeO...................	1.74	2.90	2.46	.30	(.84)	....	....
(Total Fe)............	(4.15)	(5.08)	(4.72)	(.99)	(1.62)	(.38)	(.54)
H₂O above 110° C.....	(3.45)	3.82	3.68	1.33a	1.47a	.56a	.88a
Cb....................	.69	.88	.81	....	....	....	....

a Includes organic matter.
b Inorganic matter.
A.—Composite analysis of 27 Mesozoic and Cenozoic shales.
B.—Composite analysis of 51 Paleozoic shales.
C.—General average of A and B.
D.—Composite analysis of 253 sandstones.
E.—Composite analysis of 371 sandstones.
F.—Composite analysis of 345 limestones.
G.—Composite analysis of 498 limestones.

Iron is closely associated with the lead and zinc ores in all parts of the district. All are unquestionably of similar origin and all have under-
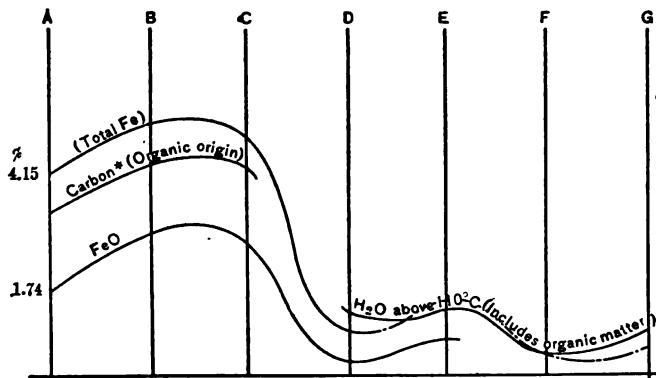
FIG. 11. Plot showing relation between metallic content and organic matter

* Percentage has been multiplied by five to bring out the relations better.

gone the same changes of solution, transportation, and deposition. If, then, the precipitation of iron was due to the same cause as that of the

[33] Clark, F. W., Analysis of rocks from the laboratory of the United States Geological Survey, 1880-1903: U. S. Geol. Survey Bull. 228, p. 20, 1904.

ores, all conditions being similar, an increase in the amount of iron pre-
cipitate would correspond to a similar increase in the amount of lead and
zinc thrown down. Therefore, in a set of analyses such as the preceding,
the varying amounts of iron recorded as present might be regarded as
indicative of the varying amounts of lead and zinc that would have been
present in the rocks analyzed if the conditions were favorable for their
deposition.

A close relation between the amount of ferrous iron or total iron,
and the amount of organic matter present in each set of rocks is strongly
indicated in A, B, and C, which, together with the almost perfect con-
tinuation of this relation through D, E, F, and G (a grand total of 1,545
analyses) seems to be sufficient evidence on which to establish the rule
that, other things being equal, the amount of iron, lead, and zinc which
exist in a sedimentary formation as original minerals, i. e., deposited at
the same time as the formation in which they exist, varies directly with
the amount of organic matter present so long as the metallic content of
the sea is not exhausted.

Organic content of the Maquoketa shale.—Because the Maquoketa
shale has been almost entirely eroded from the lead and zinc district of
the upper Mississippi Valley, the occurrence, in places at least, of con-
siderable organic matter within it has not been generally noted, although
recorded by Whitney in 1858[84] and again in 1866.[85] The Natural Car-
bon Paint Company of Freeport, Ill., was organized to manufacture
paint and certain by-products, from a so-called oil-rock obtained near the
towns of Eleroy and Mt. Carroll, Ill. This material is a shale which is
black when wet, and of light bluish-gray when dry. It can be lighted
with a match, and it burns with a similar petroleum odor as readily as
the oil-rock of the district. The shale came from the Maquoketa forma-
tion and contained 20 per cent organic matter.[86] The specimens from
Eleroy came from a shaft about 36 feet deep on the farm of R. Stader-
mann, SW. ¼ sec. 13, T. 27 N., R. 6 E. Mr. Stadermann gives the
following section for this shaft, which penetrated the lower portion of
the Maquoketa shale:

Log of shaft on the Stadermann farm

		Thickness (Feet)
14.	Soil	3
13.	Yellow, sandy gravel with many marcasite nodules..............	4
12.	Blue hard pan...	6
11.	Soapstone (a light colored clay-shale)...........................	6
10.	Black carbonaceous shale, burns readily leaving a black ash. Gives much gas by destructive distillation...................	3

[84] Whitney, J. D., Geology of Iowa, vol. I, pt. 1, pp. 358–360, 1858.
[85] Geological Survey of Illinois, vol. I, p. 176, 1866.
[86] Analysis furnished by the Natural Carbon Paint Co., Freeport, Ill.

Log of shaft on the Stadermann farm—Concluded

Thickness
(*Feet*)

9. Conglomerate (probably a mixture of clay and shells)......... ¼
8. Flat containing much marcasite.............................. 3
7. Blue clay.. ½
6. Hard limestone.. 1½
5. Black carbonaceous shale as above......................... 3
4. Layer of marcasite nodules with clay...................... ¼
3. Hard limestone containing pyrite, galena ~~and a two-inch~~ sheet
     of sphalerite... 3
2. White, loose material containing pockets of iron sulphide and
     zinc blende.. 4
1. Limestone .... ?

The largest exposure of organic shale was found about six miles southeast of Mt. Carroll, Ill., near sec. 7, T. 28 N., R. 5 E. Here it outcrops on a side hill, showing the following section:

Section along hill-side at Mt. Carroll, Ill.

Thickness
(*Feet*)

7. Soil 40
6. Gray clay.. 3
5. Hard, calcareous shale................................... 1
4. Dark gray shale, black when wet, highly organic........... 6
3. Sandy clay... 3
2. Bluish-gray shale.. 1
1. Black shale, same as No. 4............................... 4+

Float material similar to Nos. 1 and 4 in the Mt. Carroll section was seen along the slope 20 feet above No. 6, and similar material was thrown out in the excavation of a cellar about 100 paces to the south of this point, and about 40 feet above it. Very organic Maquoketa shale is also reported from west to North Buena Vista, Iowa, and from the new shaft of the Avenue Top mine at Dubuque. Whitney[37] makes the followisg statement concerning the organic character of this shale:

In the Mississippi Valley, the amount of carbonaceous matter in the Hudson-river shales [Maquoketa], has been found to form one-tenth to one-fifth of the weight of the material examined; and the quantity of volatile substances is so great, that all the specimens examined have taken fire and burned with a brilliant flame when heated in a crucible.

The following examinations will show the large amount of combustible matter present in these shales. Further examinations will be made to acquire a more exact idea of the nature of the combinations in which the carbon occurs, and especially to determine the economical value of the rock, and whether it can be profitably used as a material from which to obtain oil or illuminating gas.

SPECIMEN MARKED 'ONE MILE EAST OF SAVANNA [ILL.] FROM A WELL TEN FEET
BELOW THE SURFACE

This is a dark chocolate-colored shale, which weathers white on exposure. Heated in the closed crucible, it gives off a considerable amount of gas, which takes fire and burns with a clear bright flame.

[37] Whitney, J. D., Geology of Iowa, vol. I, pt. 1, pp. 358–360, 1858.

—6 G

The analytic determination gave:

Moisture .... .75
Volatile combustible matter................. 14.12 ⟩ Total combustible
Fixed carbon................................ 6.84 ⟩   substances.....20.96
Incombustible residuum..................... 78.29
                                           _____
                                           100.00

The residuum consists mainly of silica, the substance being a silicious shale highly impregnated with bitumen. It contains no trace of organic remains, either of animals or plants.

The rock was pulverized and digested in hydrochloric acid, which took up only a small portion, without producing any effervescence. The solution contained 0.75 per cent of lime and 3.22 per cent of oxide of iron, with traces of magnesia and the alkalies.

SPECIMENS FROM HAWLEY'S MILL, LITTLE MAQUOKETA RIVER, NEAR CHANNINGSVILLE

This is a rather dark yellowish brown shale, which contains a few fragments of *"Lingula"* and numerous minute black points, which appear to be organic matter, scattered through the mass.

Its composition was found to be as follows:

Moisture 1.20
Volatile combustible substance............. 8.16 ⟩ Total combustible
Fixed combustible substance................ 2.85 ⟩   substances.....11.01
Silicious incombustible residuum........... 87.79
                                           _____
                                           100.00

SPECIMEN FROM NEAR DUBUQUE, TAKEN FROM A SHAFT NEAR LEVINS'S DIGGINGS

A slight yellowish-brown rock, fading to light ash-color, with a tinge of blue, on being exposed for some time to the air. The rock is somewhat shaly in structure, but the layers are rather thick, and between them are numerous fossils, chiefly very minute *Lingulae*. Both this and the preceding specimen turned jet-black when heated in the closed crucible, and gave off considerable gas, which burned with a bright clear flame.

The rock contains:

Moisture .... .54
Volatile combustible substances............ 8.26 ⟩ Total combustible
Fixed combustible substances............... 8.03 ⟩   substances.....16.29
Silicious incombustible residuum........... 83.17
                                           _____
                                           100.00

The following is taken from Whitney's report[38] for the State of Illinois:

A sample from Savanna, Illinois

Insoluble in hydrochloric acid:

Clay and sand.. 73.57
Carbon 15.03
Hydrogen 1.65
Oxygen 5.39
                                              _____
                                                     22.07

Soluble in acid:

Carbonate of lime.. 1.29
Carbonate of magnesia .... .76
Alumina and protoxide of iron............................. 2.79
                                                          _____
                                                          100.48

_____
[38] Whitney, J. D., Geological Surv   of Illinois, vol. I, p. 176, 1866.

Other specimens of shale from various other localities were found to contain from five to fifteen per cent of organic matter, and the larger portion of those examined burn with a brilliant flame when heated in a crucible.

The presence of so large a proportion of carbon in the Northwest becomes still more striking from the circumstance, that neither do the rocks below, nor those above, up as high in the series as the Coal measures, contain more than the merest trace of carbonaceous matters. From the base of the Potsdam to the top of the Galena, the whole amount of carbon present in the series would not, if collected into a layer, make a deposit of more than an inch or two in thickness; but if the bituminous portion of the Hudson river-group (Maquoketa shale) at Savanna, Illinois, had all been deposited by itself in one stratum, instead of having been diffused through eighty feet of shale, that stratum would have equalled at least twenty feet, and perhaps twenty-five in thickness.[39]

A sample was collected by the author and analyzed by United States Bureau of Mines, by courtesy of Mr. David White, of the United States Geological Survey:

Analysis of sample of Maquoketa shale near Mt. Carroll, Illinois, sec. 36,
T. 24 N., R. 4 E.

Proximate Analysis		Ultimate Analysis	
Moisture	3.58	Hydrogen	1.78
Volatile matter	17.59	Carbon	13.90
Fixed carbon	3.09	Nitrogen	.44
Ash	75.74	Oxygen	6.35
	———	Sulphur	1.79
	100.00	Ash	75.74
			———
			100.00

Calorific value, determined:		Calorific value, calculated from ultimate analysis:	
Calories	1393	Calories	1504
British thermal units	2507	British thermal units	2707

Since both the oil-rock and the Maquoketa shale have been advanced as the source of ores because of their organic content, it would be of interest to determine which of the two contain the more organic matter. Chamberlin[40] gives three partial analyses of oil-rock which show 40.60, 18.31, and 15.76 per cent organic matter. F. F. Grout found 20.85 per cent in a sample from near Platteville, Wis. Two other samples from near Platteville show 22.08, and 18.65 per cent of volatile combustible matter. These six analyses average 22.71 per cent organic matter. If we regard 175 feet as the former minimum average thickness of the Maquoketa shale over the district, it would require 1.30 per cent organic matter in the shale to equal in amount that contained in the oil-rock. Such highly organic beds as are described by Whitney, in which 80 feet of shale contained the equivalent of 20 or 25 feet of pure carbon, may be exceptional, but they nevertheless show that the organic matter contained in the Maquoketa shale is unquestionably very much greater than that contained in the oil-rock.

[39] Whitney, J. D., Geology of Iowa, vol. I, pt. 1, p. 361, 1858.
[40] Chamberlin, T. C., Geology of Wisconsin, vol. 2, pp. 680–681, 1877.

That zinc and lead sulphides were actually deposited in the Maquoketa shale is indicated by the wide-spread occurrence of sphalerite and galena in the formation.

The determination of small amounts of lead and zinc in iron-bearing organic shales is very difficult so that only a few determinations of these substances in the Maquoketa shale have been made to date. The following analyses were made by R. E. Hall for the Wisconsin Geological and Natural History Survey at the writer's request:

Partial analyses of Maquoketa shale

	Lead	Zinc	Barium Oxide
Mt. Carroll, Ill...........................	.....	.....	0.032
Elleroy, Ill...............................	0.00	0.049	0.023
Graf, Iowa..............................	0.014	0.024	0.039

The first two samples came from the lower portion of the Maquoketa shale, but the third is a mixture of several grab samples taken from the section through its middle portion. None of these samples were collected for the purpose of analyzing them for lead and zinc.

Pieces of blende are reported to have been found in many places in the Maquoketa shale, although some of these reports cannot be authenticated. (Pls. XVI and XVII.) However, in the Dubuque district flats of blende and iron sulphide have been found at the Galena-Maquoketa contact and fair-sized pieces of blende 6 or 8 feet in the shale itself. At the Granville mine, 2½ miles north of Scales Mound, sec. 23, T. 29 N., R. 2 E., pieces of sphalerite an inch and more in diameter associated with iron sulphide and barite were found throughout a 150 foot tunnel in the shales, about 100 feet above the Galena dolomite and about 60 feet below the surface. At the Chicago Great Western Railroad cut one mile east of Elizabeth, blende and considerable iron sulphide were found at a depth of about 25 feet. In the Illinois Central Railroad cut at Scales Mound, pieces of blende varying from fine grains to the size of a hen's egg were found associated with iron sulphide throughout the shale exposure, which consists of its lower 25 feet. A number of bucketfulls of blende were taken from the upper portion of the Maquoketa shale near the center of sec. 10, T. 27 N., R. 1 E. According to Messrs. Trowbridge and Schockel,[41] of the Illinois State Geological Survey, the presence of blende or galena in the Maquoketa shale has been reported from the following places: (1) northeastern part of sec. 36, T. 28 N., R. 1 E.; (2) E. ½ of sec. 1, T. 26 N., R. 2 E.; (3) sec. 7, T. 27 N., R. 2 E.; and (4) northern part of sec. 32, T. 28 N., R. 2 E. In fact, at every place at which the shales have been

[41] Personal communication.

A. Blende from Maquoketa shale, Scales Mound, Ill.

B. Blende, barite, and dolomite from Maquoketa shale, Granville mine, Scales Mound, Ill.

C. Blende and dolomite from Maquoketa shale, Granville mine, Scales Mound, Ill.

D. Blende and iron sulphide from Maquoketa shale, Scales Mound, Ill.

E. Blende and dolomite from Maquoketa shale, Scales Mound, Ill.
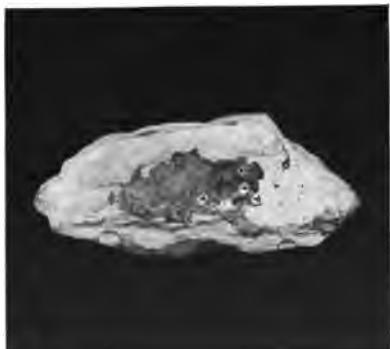
F. Blende and iron sulphide from Maquoketa shale, Scales Mound, Ill.

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examined by the writer with this purpose in view, zinc or lead has been found.

ORIGINAL CHARA 'ER OF THE ORE MINERALS IN THE MAQUOKETA SHALE

In all the discu sions concerning the origin of the ores of this district, no proof has been given that the ores were original in the rock from which they were dissolved before they were concentrated in their present positions. Davis, in his consideration of the oil-rock, described crystals of galena and sphalerite in this impervious shale, and thus came nearer than any other writer to showing that the ores were original in the rock which is regarded as their immediate source. Many analyses of limestones have been made to show that they contain small amounts of lead and zinc, but because of their porous character and the free circulation of water through them, especially in this district, it is impossible to say that even the small percentage shown by the average of these analyses is original.

Although it is probably true that the oil-rock and limestones in general contain small amounts of original lead and zinc compounds, it is believed that the Maquoketa shale offers a more probable source for the ores in this district, because of the fact that it is impervious and yet contains the ore minerals at widely separated localities, and at depths ranging from 20 to 100 feet below the surface. The impervious character of the shale precludes any possibility that the ores have been introduced after the deposition of the shale. It is also certain that the ores could not have come up from the Galena dolomite.

ADEQUACY OF THE MAQUOKETA SHALE AS THE SOURCE OF THE ORES

The following statement is quoted from Chamberlin:

At my suggestion Mr. I. M. Buell made an estimate of the amount of impregnation of the rock that would occur, if the entire quantity of ore taken from the Potosi district were uniformly distributed through the adjacent rock. This district was selected because (1) it has been one of the most productive, (2) has definite outlines, (3) a somewhat uniform distribution of crevices, and (4) is withal one of the most concentrated districts of the whole region. In determining the limits of the district, a margin outside the outermost crevices was allowed equal to half the average distance between the crevices, i. e., the outside crevice was supposed to draw only as much from the territory outside as from that between it and its neighbor crevice. As the basin occupied by the district extends some distance on every side, this is a very moderate assumption. Furthermore, it was assumed that only 100 feet in depth had been leached in the derivation of the ores, although probably twice that amount of rock originally lay above the base of the deposit. The result was *one-fourteen-hundredth of one per cent*, or a little more than seven millionths of the rock, a quantity that may seem surprisingly small to those who, by dwelling upon the relative value of the ores magnify their relative quantity, a quantity certainly small enough to answer certain inconsiderate objections to the theory of derivation of the ores from the enclosed rock, based on the want of ocular evidence of their metalliferous character.[a]

_____
[a] Chamberlin, T. C., Geology of Wisconsin, vol. 4, p. 538, 1882.

If we assume the Maquoketa shale to have averaged 175 feet thick over the whole district, it would require, according to the above figures (0.000,004), .24 per cent original metallic sulphides in the shale to account for the ore mined in the Potosi district; or, if we assume that half of the material was lost in the transfer from the shales to the dolomite, (0.000,008), .12 per cent. If we may further assume that the Potosi district is a representative one, then these figures are applicable to the upper Mississippi Valley district as a whole.

It is possible to check the above figures by estimating the amount of shale that has been eroded from the district, and has thus been available as a source of ore, and by comparing it with the amount of ore produced to date, making a liberal allowance for that which may still be discovered. Such a computation must necessarily be crude, but it will be seen that even when liberal allowances are made to cover all reasonable possibilities of ore being lost in the transfer and of ore yet to be discovered, the per cent of original ore in the shale will still be below rather than above the figures of Chamberlin.

If a polygon be drawn so that its angles are at Blanding and Stockton, Ill., Monroe and Highland, Wis., and Guttenburg, Iowa, it will include the general mining district, although ore has also been found in paying quantities outside this area, notably south of Elizabeth and Stockton, Ill., north of Monroe, Wis., north of Highland, Wis., southwest of Dubuque, Ia., etc. The area of this polygon is about 2,025 square miles. Considering the Maquoketa shale to have averaged 175 feet thick over the area, and to have had a specific gravity of 1.9, there would have been roughly, 586,590,000,000 tons of shale to furnish the ore. The yield of the district in lead and zinc ores to date has been as follows:

Production of lead and zinc ore in the northern Mississippi Valley district to 1908

	Lead ore (tons)	Zinc ore (tons)
Total up to 1904...	611,975a	
Total up to 1905...		450,000a
1904...	1,000b	
1905...	1,500b	33,000a
1906...	2,100c	43,000b
1907...	4,000c	54,000d
1908...	4,400d	59,000d
	624,975	639,000

a U. S. Geological Survey Bull 294, p. 9, 1906.
b Estimated.
c The Mineral Industry for 1906, p. 514.
d Estimate based upon the production of Wisconsin as given in Mineral Resources of the United States for 1908, p. 639.

This gives a grand total of 1,263,975, or roughly, 1,264,000 tons of lead and zinc ores mined to 1909, which, although not all mined as

A. Blende from Maquoketa shale, Granville mine, Scales Mound, Ill.

B. Blende from Maquoketa shale, Scales Mound, Ill.

C. Blende and iron sulphide from Maquoketa shale, Scales Mound, Ill.

D. Blende from Maquoketa shale, Scales Mound, Ill.

E. Blende from Maquoketa shale, Scales Mound, Ill.

F. Iron sulphide seam in Maquoketa shale, Elroy, Ill.
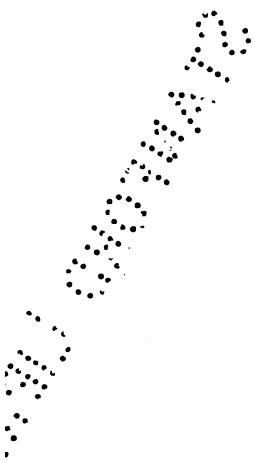
sulphides, were originally sulphides and can be so classed here. This amount of ore would require an original percentage of 0.000,002,155 in the shale. If, for the sake of argument, we assume that there is as much ore left as mined, it would require a percentage of 0.000,004,310. If we farther assume that there has been a loss of 50 per cent in the process of transfer from the shales to the dolomite, 0.000,008,620 per cent of original metallic sulphides would be required.

The preceding percentages are approximately one-third of those obtained by Chamberlin for the Galena dolomite, and about one-half of those obtained by applying Chamberlin's method to the Maquoketa shale, i. e.· considering 175 feet of shale as against 100 feet of the dolomite.

On a previous page it was stated that where the Maquoketa shale had been examined with respect to its metallic content, lead and zinc sulphides had either occurred in pieces sufficiently large to be determined by the eye, or they have been shown to be present by chemical analyses. In three cases 0.104, 0.049, and 0.038 per cent of combined lead and zinc sulphides were found, showing conclusively that there can be no question concerning the adequacy of the Maquoketa shale as the source of the ores.

VERTICAL DISTRIBUTION OF THE ORES

It is a fact generally recognized by all who are familiar with this district, that there is a general order of deposition of the ores both vertically and laterally. The large predominance of the lead over the zinc mined in the early days was due not necessarily to the greater value of the former, but rather to the fact that the lead ores lay nearer the surface than the zinc and iron ores, which are usually below the water table.

Chemically, a solution must be either acid, neutral, or basic. Solutions which have passed through the small pores of a limestone for a considerable distance, as postulated by the Galena-oil-rock theory, could not be other than alkaline or neutral in nature. Meteoric waters directly from the surface carrying metals which have been taken into solution by the oxidation of sulphides are characteristically acid, particularly so in the presence of iron sulphide, the oxidation of which forms free sulphuric acid.

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4.$$
$$4FeSO_4 + 7H_2O + O_2 = 2Fe_2O_3.3H_2O + 4H_2SO_4$$
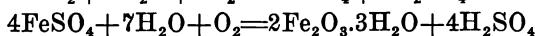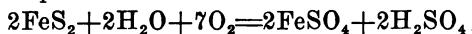
In the ordinary qualitative or quantitiative chemical determination of a lead and zinc solution, the lead is first precipitated in the presence of an acid, and then the zinc in the presence of an alkali. If the lead has not first been removed, both of the metals will be precipitated to--

gether from the basic solution. Buckley and Buehler[48] have shown that the sulphides of lead, zinc, and iron are precipitated from a neutral solution in an intimate mixture, and that lead and zinc from an alkaline solution in a similar condition. If the solution is acid, however, the lead sulphide is thrown down first, the zinc sulphide second, and the iron sulphide last.

From these facts it is apparent that the vertical distribution of the present ore bodies cannot be explained by their direct precipitation from such solutions as are necessitated by the Galena-oil-rock theory and its modifications. On the other hand, the vertical arrangement of the ores is that which would result from their precipitation from descending acid solutions such as would have been present if the ores had been derived from Maquoketa shale.

A like succession in the deposition of the ores is shown also in the linings of cavities and other openings. The substance next to the wall rock, i. e. the first to be deposited, was iron sulphide in the form of pyrite and marcasite followed by sphalerite and galena in order. This universal succession has produced banding of the ores which is so characteristic that there seem to be but two possible explanations for it. Either the banding represents the order of precipitation of these metals from a common solution, or the solutions which first reached these points had been depleted of their lead and zinc and contained only iron. Those who favor any of the oil-rock theories might claim that the former is the true explanation, and that the vertical distribution of the ores is due to deposition from ascending solutions, were it not for the fact that field observations indicate that the iron sulphide tends to mark the extreme limit to which the mineralizing solutions have penetrated, and not the point at which they have been introduced. This being true, it follows that the iron sulphide is deposited next to the country rock because it is the most soluble of the sulphides of the ore metals and is therefore liable to be carried first, and precipitated last. It would therefore tend to be carried the farthest. The second layer is composed of sphalerite because it is more soluble and less readily precipitated than the galena. As the surface and water table are lowered by erosion, the lead and zinc are carried farther and farther down, resulting in the banding described above.

AREAL DISTRIBUTION OF THE ORES

For the upper Mississippi Valley lead and zinc district three possible reasons for the localization of the ores in the sediments have been

    [48] Buckley, E. R. and Buckley, H. A., Geology of the Granby Area: Missouri Bureau of Geology and Mines, vol. IV, 2d series, p. 107, 1905.

outlined[44] on the assumption that the Maquoketa shale is the source of these ores—

(a)   Local abundance of the metals in solution.

(b)   Local abundance of the organic reducing matter.

(c)   Locally peculiar organic matter, leading to particular efficiency in producing deposition.

Local abundance of the metals in solution.—Although we have no reason to suppose that the Ordovician seas were any richer in metallic compounds than the seas of the present time, there is good reason for believing that there did exist, as now, segregations of minerals within the earth's crust, with the result that some districts were rich in some of the metallic ores, whereas others were destitute of these; and that the water[45] of the streams draining the mineralized areas contained abnormally high percentages of these metals in solution, with the result that at the mouths of these streams, or within bays into which they emptied, there existed a local abundance of the metals in solution.   The evidence for this hypothesis may be briefly summarized as follows:

(1)   It is known that the water of rivers draining mineralized areas is abnormally rich in the metals of the region drained.

(2)   The presence of an unconformity between the Maquoketa and Galena formations, found elsewhere and indicated here by an abrupt change of fossils, by the presence of what have been taken to be small pebbles near the base of the Maquoketa shale, and by the large amounts of organic matter within it, indicate shallow water conditions such as exist in embayments or in areas near shore.

(3)   The irregular distribution of the lead and zinc ores over the district and the occurrence of copper near and at Mineral Point, Wis., where it has been mined to the value of half a million dollars, and near Gratiot, Wis.,[46] whereas even traces are almost lacking elsewhere in the district, show conclusively that there were differences in the character of the solutions percolating through the rocks at different places, or that the precipitating agents were not everywhere alike.   If it were possible to determine the character of the Maquoketa shale at these points, the question as to the varying character of the precipitating agents might be settled.   Unfortunately for this purpose, however, the shale has been eroded.   Nevertheless it is certain that there is no apparent difference in the character of the Galena dolomite or the oil-rock at these points. If this were shown to be true of the overlying shale as well, it would follow almost as a corollary, that, since there was no difference in the

[44] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294 p. 133, 1906.

[45] Chamberlin and Salisbury, Geology, vol. I, 1904, table opposite page 102, for variations in the composition of river water.

[46] Cox, G. H., Copper in southwestern Wisconsin: Min. and Sci. Press, vol. 99, No. 18, p. 529, Oct. 20, 1909.

precipitating agents there must have been differences in the character of the solutions at the different places.

Local abundance of organic reducing matter.—The Maquoketa shale and the oil-rock are the most carbonaceous formations ever known to have been present in this district. There are, however, many formations in other districts which contain organic matter in much greater quantities than either of these, and yet are not known to have been instrumental in the production of ore deposits. It is evident, therefore, that the local abundance of organic reducing matter in the district is not sufficient in itself to account for its location.

Locally peculiar organic matter, leading to particular efficiency of producing deposition.—By the following experiment Bain[47] has attempted to show that the oil-rock has an exceptional precipitating power:

To one-fourth gram of air-dried oil-rock and 100 cubic centimeters of water, were added 0.005 grams of iron in the form of ferric sulphate. This was acidified with 5 grams of H_2SO_4, and a similar portion was rendered alkaline with .1 gram KOH. After standing a week the amount of iron present as a ferrous salt was determined with $KMnO_4$. It was found that in the acid solution the amount was 0.0035 gram and in the alkaline 0.0012 gram.

In order to compare the relative reducing powers of the Maquoketa shale and the oil-rock, a sample of the shale was tested[48] by the methods employed by Bain. Using small quantities of materials as were used by Bain, it was found that under the same conditions the quantity of ferrous salt present in the acid solution at the end of a week was 0.0037 gram and in the alkaline 0.0017 gram.

The result of this experiment shows that the organic matter of the Maquoketa shale and that of the oil-rock have practically the same reducing power, which is, probably, abnormally high for shales in general. However, it should be borne in mind that if organic matter in general is able to precipitate lead, zinc, and iron sulphides from solution, there is very little importance to be attached to the peculiar reducing efficiency of any particular kind of organic matter. From this, it follows directly, that whether or not the areal distribution of the ores is due locally peculiar organic matter, leading to particular efficiency in producing precipitation, depends entirely upon whether or not organic matter in general is able to cause the precipitation of the sulphides of lead, zinc, and iron from solution. Inasmuch as iron sulphide is in general the least readily precipitated from a solution of these three metals, and is so commonly and characteristically associated with formations rich in organic matter, such as the "Coal Measures," it is believed that field evidence indicates strongly that ordinary organic matter *is*

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[47] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294 p. 133, 1906.
[48] Determinations made by C. W. Kenniston, Mining Experiment Station, Missouri School of Mines and Metallurgy, Rolla, Mo.

able to produce the precipitation of these metals and therefore, that
"particular efficiency" has probably not been a prominent factor in con-
trolling the areal distribution of the ores of this district.

<div align="center">CONCLUSIONS</div>

From the foregoing discussion it is concluded that the areal distri-
bution of the ores in this district is not due to any one condition, but
is the result of a combination of causes, among the most important of
which are the three to which reference has been made. This conclusion
is in accord with the view that the ores were derived from the Maquoketa
shale. The organic matter within this shale and the nature of the uncon-
formity at its base indicate that it was deposited in shallow water, or near
the shore at places where streams emptying into the sea would supply
an abnormally large quantity of the metals in solution. In 1866
Worthen[49] stated not only that certain portions of the Maquoketa shale
of Illinois are rich in organic matter, but also that the richly organic
varieties of the shale are confined to the lead region. In Iowa it is
known that this shale, where penetrated by the Avenue Top mine at
Dubuque, and at Buena Vista is highly organic, whereas, to the west, in
places at least, it is largely calcareous. It is thus seen that the organic
character of the Maquoketa shale is limited, roughly at least, to the min-
eralized region. The high reducing power of the organic matter in the
shale has already been shown.

It is a striking fact that the non-glaciated area from which the
Maquoketa shale has been eroded corresponds almost exactly to that of
the lead and zinc district. (See Pl. IX.) There are, however, some
discrepancies between the known mineralized area and the total area
from which the Maquoketa shale has been eroded, but some of them may
be more apparent than real. This may be the case in north-central
Illinois, where the mapping may not be accurate. The Maquoketa shale
may be more extensive than is indicated on the present map of the area,
(Pl. XXI) or, on the other hand, the area may be mineralized. Ore has
been found in a number of places beneath the drift to the south and east.
Even if the area is as well mineralized as the richest portions of Wis-
consin, the chances are very small that ore deposits would have been
found under so heavy a sheet of glacial drift as is present over this area.

Further, it is possible that a considerable portion of the area was
stripped of its shale by the glaciers and that this may account for the
fact that the boundaries of the driftless area and those of the Maquoketa
shale do not coincide.

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[49] Worthen, A. H., Geological Survey of Illinois, vol. I, pp. 137–140, 1866.

Or, finally, the Maquoketa shale may not have had the proper composition everywhere to cause mineralization in the underlying rocks, and, consequently, when it was removed, ore deposits were formed in some places and not in others.

With the exception noted above, there is a general agreement between the area from which the Maquoketa shale has been eroded and that of the lead and zinc district. To the west the ores have been worked as far as the Galena dolomite has been exposed by the erosion of the shale. To the south along the Mississippi River ore occurs as far as Savanna and Mt. Carroll, where the shale is still present. To the east and north the district has been limited by the erosion of the Galena dolomite, which is the ore-bearing formation. The character of the Maquoketa shale under the thick sheet of drift to the east of the Wisconsin anticline is not known.

At the northern and eastern portions of the district ore has been found in the top of the Platteville limestone. This occurrence is thought to be due in general to the descent of ore from the overlying formations during the process of secondary concentration. Ore is not found in this formation where it is far from the surface.

The occurrence of small amounts of galena in the Prairie du Chien dolomite north of the Wisconsin River seems also to have been due to descending solutions inasmuch as the deposits are small and occur as fillings of openings which are directly connected with the surface and which die out at shallow depths.

IRREGULARITIES OF ORE DEPOSITS WITHIN THE DISTRICT

Within the general lead and zinc region are local mining districts more or less separated from each other, and within these local mining districts are heavily mineralized areas, whereas others are practically barren. It is true that the finding of new mines has made it practically impossible to draw sharp lines between some of these, but it is probable that even in the future some of these areas, at least, will remain somewhat distinct.

Such segregations are believed to be due to an irregular distribution of the original metallic sulphides in the Maquoketa shale, whereas the localization of the deposits within the minor districts is thought to be due to local concentration of solutions in favorable openings during the ordinary processes of erosion of the shale. During the processes of erosion, hills and valleys are always formed. The water from the hills running into a constricted valley may concentrate solutions from a large area, especially where the underlying formation is impervious. The waters on passing from the Maquoketa shale sink into the fractures,

joints, and pores in the Galena dolomite, where the minerals contained in the solutions are precipitated under favorable conditions. In this manner ore deposits a mile or even a number of miles apart may be simply and adequately explained.

RELATION OF ORES TO ASSOCIATED MINERALS

The chief minerals associated with the lead and zinc ores are, in the order of their abundance, calcite, iron sulphide (marcasite and pyrite), barite, and traces of copper ores. It is believed that the history of the copper and iron minerals is the same as that of the lead and zinc ores and hence needs no further discussion here. As a rule the introduction of the calcite was later than that of the ores of the first concentration. It is probable that it was derived largely from the Galena dolomite, although the overlying shales do contain abundant calcium carbonate.

Barite occurs in the vicinity of Dubuque and Guttenburg, Iowa, Platteville, Meekers Grove, New Diggings, Shullsburg, Mineral Point, Dodgeville, Montfort, Wis., and in traces in practically all parts of the mining district. At the Gritty Six mine in Wisconsin, SW. ¼, sec. 21, T. 2 N., R. 1 E., where the barite is probably most abundant, it contains small pieces of galena and is associated with large amounts of iron sulphide. The source of the barite may be either the Galena dolomite or the overlying Maquoketa shale, as both contain barium compounds, especially the shale. Clark's analyses[50] show that in general barium is present in greater amounts in shales than in limestones. Clark[51] further states that "P. P. Bedson[52] found barium to be present in notable amounts in an English colliery water; and T. Richardson[53] has described a deposit of barite from a similar solution. Similar deposits from other English collieries have been reported by F. Cowles,[54] who analyzed samples containing from 81.37 per cent to 93.35 per cent of BaSO$_4$. The pipes carrying the water from the mines which yielded these sediments were often choked by them, the barium sulphate being rarely absent and frequently their chief constituent."

The average of three analyses of Maquoketa shale from Mt. Carroll and Eleroy, Ill., and Graf, Iowa, shows 0.031 per cent BaO (p. 84). Many pieces of barite as large as a small hen's egg are found in the Maquoketa shale, associated with the zinc blende and iron sulphide at the Granville mine, near Scales Mound, Ill. Pieces of barite[55] weighing 6 or 8 pounds have been found at the Galena-Maquoketa contact at Dubuque, Ia. The presence of so abnormal an amount of barium in

[50] Clark, F. W., Analyses of rocks from the laboratory of the United States Geological Survey, 1880–1903: U. S. Geol. Survey Bull. 228, 1904.
[51] Clark, F. W., Data of Geochemistry: U. S. Geol. Survey Bull. 330, p. 428, 1908.
[52] Jour. Soc. Chem. Ind., vol. 6, p. 712, 1887.
[53] Rept. Brit. Assoc., p. 54, 1863.
[54] Proc. Roy. Chem. Soc., vol. 46, p. 368, 1889.
[55] Personal communication from John Babcock, Dubuque, Iowa.

the shale and its general association (although in very small amounts) with the ores in all the districts and at all horizons in the Galena dolomite and the Maquoketa shale indicate that the ores and the barium have a like origin, and the presence of crystals of galena within the barite shows at least that the two have in some cases been precipitated at the same time.

The original condition of the barium in the shale has not been determined, but it probably exists both as carbonate and sulphate. Because of the extreme insolubility of the sulphate, it seems reasonable to suppose that the barium was probably carried as the carbonate, which is soluble either in water containing CO_2 or in a solution of a bicarbonate. Water, on penetrating the Maquoketa shale along some porous bed, as a seam of limestone or sandy shale, is soon depleted of its oxygen and becomes neutral or alkaline. Such waters would readily take into solution any barium carbonate present and carry it out of the shale at springs or by slow seepage, into the openings in the Galena dolomite. Here, on meeting with solutions directly from the surface, containing H_2SO_4 and its salts, precipitation of the barium as barite would occur.

If, however, the barium has been derived from the Galena dolomite, it has doubtless been carried in solution as a carbonate which, on passing through the wall rock into the openings, encountered acid surface waters which caused the precipitation of the barium as barite.

CHEMISTRY OF THE ORES
INTRODUCTORY STATEMENT

All of the ores of this district whether original or secondary have at some time been in solution. A complete knowledge of the origin is not possible, therefore, without an understanding of their chemistry. For convenience of discussion the subject may be divided into three parts —solution, transportation, and deposition.

SOLUTION

The number of times the ore minerals have been taken into solution and deposited is immaterial from the chemical standpoint if the conditions have been similar. All of the ores have been taken into solution at least twice, once from their parent igneous rock, and once from the sedimentary rock from which they were last concentrated. In each case the solution is believed to have resulted from the oxidation of metallic sulphides under weathering conditions, which usually results in the formation of the sulphates.

$$PbS+2O_2=PbSO_4$$
$$ZnS+2O_2=ZnSO_4 \text{ (probably carried as } ZnSO_4+7H_2O)$$
$$2FeS_2+2H_2O+7O_2=2FeSO_4+2H_2SO_4$$
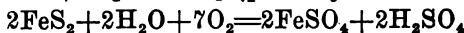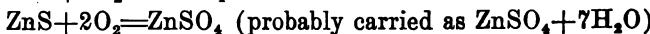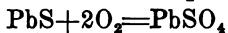
The sulphates of zinc and of iron are very soluble compounds.

Next to the sulphates the carbonates are the most likely to form. The carbonate of zinc is very common in the oxidized zone, that of lead is rare, but the mineral is present, but that of iron has not been observed. The alteration of the sulphides to carbonates is believed to be through the sulphates, thus:

$$PbSO_4+CaCO_3+2H_2O=PbCO_3+CaSO_4.2H_2O$$
$$ZnSO_4+CaCO_3+2H_2O=ZnCO_3+CaSO_4.2H_2O$$
$$FeSO_4+CaCO_3+2H_2O=FeCo_3+CaSO_4.2H_2O$$
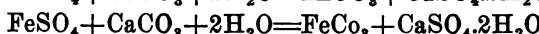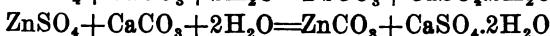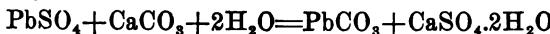
The sulphates and carbonates of iron and zinc are readily formed in the laboratory, as are also those of lead after the lead is once in solution. It has been indicated by the work of Winchell[56] and of Grout[57] and Buehler and Gottschalk[58] that the rate of solution of sulphides varies directly with the area exposed. The original galena in the Maquoketa shale was finely disseminated and hence much more readily soluble than in its present state of first concentration in the top of the Galena dolomite. Buehler and Gottschalk have shown also that the presence of one sulphide may greatly effect the solubility of others, particular attention being called to the increased solubility of the sulphides of zine and lead in the presence of that of iron. This indicates that the ores as they existed in a finely disseminated form in the Maquoketa shale were much more readily taken into solution than at present in their segregated condition. This is especially true of the lead sulphide, for in its characteristic deposits it is coarsely crystallized and scarcely a trace of iron sulphide can be found.

TRANSPORTATION

In the transportation of the lead, zinc, and iron salts from their parent igneous rock to the sea, as well as in their later transportation from their parent sedimentary formation to the points of primary concentration, they are believed to have been carried in the form of sulphates and carbonates, but very largely as the former. Water which passes through an organic shale becomes reducing in character so that inasmuch as the oxidation of sulphides generally precedes their solution, it is only the water which passes over the surface or through the oxidized portion of the shale that is the main carrier of the metals. Such solutions are acid in nature if the shales contain sulphides of iron, pyrite and marcasite, which are the most common of all sulphides, and on oxidizing to the sulphate, liberate one molecule of free sulphuric acid, and upon oxidization to the hydrate, two molecules of this acid.

[56] Winchell, A. N., Oxidation of pyrite: Econ. Geol. Vol. II, p. 290, 1907.
[57] Grout, F. F., Discussion of Winchells' papers—Oxidatiod of pyrite: Econ. Geol., Vol. III, p. 532, 1908.
[58] . and Gottschalk, V. A., Oxidation of sulphides: Econ. Geol., Vol. V, ,p. 28, 1910

$$2FeS_2+2H_2O+7O_2=2FeSO_4+2H_2SO_4$$
$$4FeS_2+11H_2O+15O_2=2Fe_2O_3.3H_2O+H_2SO_4$$
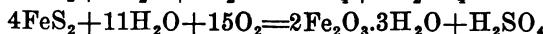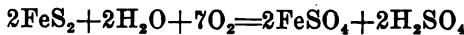
It therefore seems probable that most of the ores were carried as sulphates. Clark[59] makes the following statement in regard to the transportation of zinc:

"None of these species needs further mention except goslarite, $ZnSO_4.7H_2O$, which is the compound of zinc existing in mine waters and zinciferous springs. When zinc is dissolved from an ore body by solution, it is carried in this form."

DEPOSITION

Whatever may have been the cause of the deposition of the ore from solution, it acted slowly. Openings which had a direct outlet so that the flow within them was rapid, contain no ore. Selective attraction of like for like, or surface tension, apparently added the last bit of force necessary to produce precipitation or crystallization, for the deposits line the walls just as readily as they do at the bottoms of the openings. Neutralization alone is not sufficient to cause the precipitation of the ores as sulphides.

Sulphides first oxidize to sulphates, and before transportation can take place may be precipitated by the presence of a carbonate, such as $CaCO_3$. Most of the carbonate ores as exist in the district give evidence to show that they have been altered *in situ* in this manner.

Various agents have been suggested as the cause of the precipitation of the ore minerals—hydrogen sulphide, sulphides of the alkalies and alkaline earths, organic matter, and the compounds of metals having a greater affinity for sulphur than those in solution.

(1)   Hydrogen sulphide—
$$ZnSO_4+H_2S=ZnS+H_2SO_4$$
$$ZnCO_3+H_2S=ZnS+H_2O+CO_2$$
$$PbSO_4+H_2S=PbS+H_2SO_4$$
$$PbCO_3+H_2S=PbS+H_2O+CO_2$$
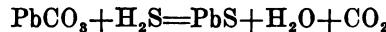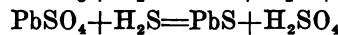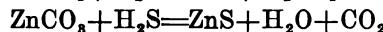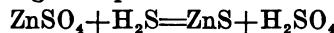
H_2S produces no precipitation of iron in solutions containing dilute inorganic acids. A precipitation of FeS may be produced by the prolonged action of H_2S.

Zinc is precipitated completely from an alkaline solution but only in part from one which is neutral or slightly acid. From this statement it is evident that acid solutions would first deposit their lead, and later as they are neutralized by the limestone, their zinc and iron.

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[59] Clark, F. W., Data of Geochemistry: U. S. Geol. Survey Bull. 330, p, 580, 1908

Further, all the above reactions are accompanied by the liberation of free acid, which, unless neutralized as fast as formed, would further hinder the precipitation of the zinc and iron.

(2) Sulphides of the alkalies and alkaline earths, represented by CaS—

$$ZnSO_4 + CaS + 2H_2O = ZnS + CaSO_4.2H_2O$$
$$ZnCO_3 + CaS = ZnS + CaCO_3$$
$$PbSO_4 + CaS + 2H_2O = PbS + CaSO_4.2H_2O$$
$$PbCO_3 + CaS = PbS + CaCO_3$$
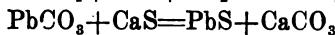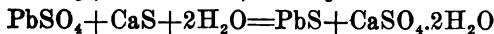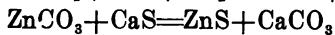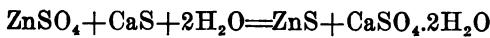
CaS precipitates black and insoluble FeS, which on standing is oxidized to $FeSO_4$. The sulphides of iron, and probably those of lead and zinc, are soluble in an excess of Na_2S, probably also in CaS.

(3) Organic matter—

$$ZnSO_4 + 2C = ZnS + 2CO_2$$
$$PbSO_4 + 2C = PbS + 2CO_2$$
$$4FeSO_4 + 2C = 2FeS_2 + 2FeCO_3 + 5O_2$$
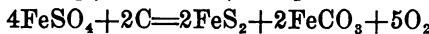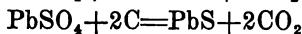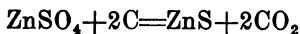
Pure carbon is very inert chemically at ordinary temperatures and it is not to be inferred from the preceding equations that it is considered to act as a reducing agent. The real precipitating agents are the various hydro-carbon acids and gases given off in the decay of organic matter, for which C is here used.

(4) It is a well-known fact that metals vary in their affinity for other elements. Schurmann[60] has shown that the metals have an increasing affinity for sulphur in the following order: manganese, thallium, arsenic, iron, cobalt, nickel, zinc, lead, tin, antimony, cadmium, bismuth, copper, silver, mercury, and palladium. He has shown that if the sulphide of any one of this series is brought into contact with the oxidized salt of another which has less affinity for sulphur, a double exchange will ensue, resulting in the precipitation of the latter as a sulphide—

$$ZnSO_4 + FeS_2 + O_2 = ZnS + FeSO_4 + SO_2$$
$$ZnCO_3 + FeS_2 + O_2 = ZnS + FeCO_3 + SO_2$$
$$PbSO_4 + FeS_2 + O_2 = PbS + FeSO_4 + SO_2$$
$$PbCO_3 + FeS_2 + O_2 = PbS + FeCO_3 + SO_2$$
$$PbSO_4 + ZnS = PbS + ZnSO_4$$
$$PbCO_3 + ZnS = PbS + ZnCO_3$$
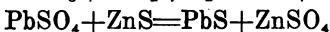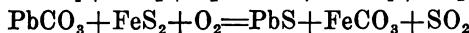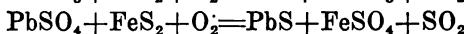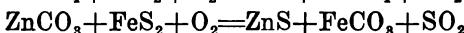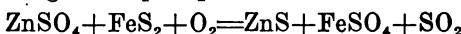
From this it follows that in a mixture of the sulphide of iron, zinc, and lead, the iron would go into solution first, the zinc second, and the lead last. But it is not to be assumed that all the iron must be dissolved and carried away before any of the zinc could go into solution, etc., for

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[60] Schurmann cited by Buckley and Buehler after VanHise, The Geology of the Granby area: Missouri Bureau of Geology & Mines, vol. IV, 2d series, p. 90, 1905.

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where the grains are scattered there is ample opportunity for some of the lead and zinc to be taken into solution at the same time as the iron, and field evidence goes to show that two or more of these metals have been carried in solution at the same time. It is also to be noted that when these minerals are in contact, the presence of iron sulphide will greatly facilitate the solution of the sulphides of lead and zinc.[61]

All of the four methods for the precipitation of the metals as sulphides as outlined above are possible, so that it then remains to be determined which of these precipitating agents are present in the district. Hydrogen sulphide is produced in nature by the reduction of alkaline sulphates by organic matter and the carbonization of the resulting sulphide after the following reactions:

$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$
$$Na_2S + CO_2 + H_2O = Na_2CO_3 + H_2S$$
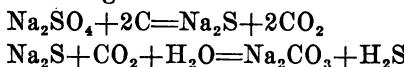
The sulphates of alkalies and alkaline earths, organic matter, and carbon-dioxide are undoubtedly present and, therefore, H_2S has probably played a part in the precipitation of the ores. However, whether the precipitation of the ore as a sulphide is due to hydrogen sulphide, the sulphides of alkalies and alkaline earths, or hydro-carbons, it loses much of its importance when it is noted that all of these, and hence the precipitation of the ore by them, are due to organic matter. It is believed that this organic matter was contained in part in the Galena dolomite, in part in the oil-rock, and in part has been washed into the openings from the surface. In accordance with this belief is the tendency shown by the ore in places to favor the darker (more organic) layers of limestone.

The fourth possibility, the precipitation of the ores by metals of greater affinity for the oxidized sulphur molecule, although closely related to the order of precipitation of the ores, is thought not to have been effective in causing the precipitation of the ores as sulphides, for pseudomorphs of sphalerite after iron sulphide, and galena after sphalerite and iron sulphide, if present at all, are certainly very scarce. This force has been active in the precipitation of some of the carbonate ores, as shown by the pseudomorphs of smithsonite after calcite.

SUMMARY

In advancing the Maquoketa shale as the source of the ores it is not intended to convey the idea that these shales are the only formation in this district that contain original metallic sulphides. Traces of lead, zinc, and iron sulphides are common in many formations and it is believed that all the formations that are now, or ever have been, present in this district contained a small percentage of these compounds as original precipitates.

[61] Buehler, H. A. and Gottschalk, V. H., Oxidation of sulphides: Econ. Geol., vol. V, p. 28, 1910.

Traces of sulphides, especially those of zinc and iron, have been found in such positions in the Prairie du Chien and Platteville formations as to suggest rather strongly that part of them at least are original in these formations. It therefore seems reasonable to suppose that the Potsdam sandstone, the Prairie du Chien dolomite, the St. Peter sandstone, the Platteville limestone, the Galena dolomite (including the oil-rock), the Maquoketa shale, and even the Niagara dolomite, all contained at least a trace of these metallic sulphides as original minerals. It also seems probable that if this district were ever overlain by other formations, they also contained some small amount of metallic sulphides.

Unquestionably the lead, zinc, and iron ores originally came from pre-Cambrian igneous rocks, doubtless somewhere to the north where such rocks have been shown to contain these metals. They were taken into solution through the ordinary processes of erosion, carried to the sea by streams, and there deposited with the material of the Maquoketa shale, although in the time between their solution from the igneous rocks, and their deposition with the shale they may have been precipitated with other formations and later redissolved. After the deposition of the Maquoketa shale and such other formations as may have been laid down, the retreat of the sea, and the erosion of the overlying beds, the ore particles were again taken into solution by ordinary meteoric waters during the erosion of the shale and carried downward and laterally into the porous and fractured Galena dolomite where precipitation of the ore occurred, due largely to the reducing action of organic compounds. In so far as secondary concentration has taken place after the introduction of the ores into the Galena dolomite, the ores were again taken into solution and carried downward to be precipitated in the same manner as before.

The Maquoketa shale is advanced as the probable source of the lead and zinc ores of this district for the following reasons:

1. The thickness of the shale, its organic content, and the high efficiency of its hydro-carbons as precipitating agents.

2. Lead and zinc have been found in such positions as to show beyond a doubt that they are original in this formation and in quantities adequate to account for the ore deposits.

3. This hypothesis of source explains the vertical distribution of the ores and the order of their deposition upon the wall rock without appealing to secondary concentration.

4. It accounts for the areal distribution of the ores, the location of the district, and especially the variations within it.

5. It accounts for the associated minerals as well as for their distribution.

6. It accounts for such ore deposits as the Baxter and Dutch Hollow mines, situated on top of oil-rock ridges, as well as for those deposits which occur in the bottoms or on the limbs of the oil-rock basins.

7. It accounts for the ore ranges and for the marked tendency for the ore deposits to favor valleys.

8. It accounts for the large excess of the zinc over the lead mined in the northern portion of the district, where it occurs in the lower portion of the Galena dolomite, and the excess of the lead over the zinc in the southern portion, as around Dubuque, Galena, Stockton, and Elizabeth, where the separation of the lead from the zinc has been more marked, and the lead ore occurs in the top of the Galena formation.

9. It is believed that it accounts for all the features of the ore deposits in a manner more simple and complete than any other hypothesis heretofore proposed.

CHAPTER VI—ECONOMIC CONSIDERATIONS

PROSPECTING

During the days in which lead was the chief product of this district, prospecting was carried on by means of shafts. Because of the depth at which the ore is now found, the use of shafts in exploratory work has been almost entirely abandoned, drilling having been found to be very much cheaper. Holes are drilled to the desirable depth at a cost ranging from 60 cents to $1.25 a foot, depending upon the demand for drillers and the size of the contract. At the present time 75 cents is about the average cost of drilling, although some companies have reported a cost of less than 50 cents a foot where they have owned the drills. Diamond drills have been tried, but the ground has been found to be too open and flinty to permit their successful use. It is customary to sink the drill holes until the oil-rock or the clay bed at the base of the Galena is encountered, and it is not bad practice to sink every fifth or tenth hole through the glass-rock, although this is not so applicable to the Illinois field as to that of Wisconsin. In the upper portion of the rock where no ore is expected, the drillman is allowed to drill as far as he wishes before sludging, although the cuttings are always examined. As the ore-bearing horizon is approached the distance between sludging is usually cut down to two feet, and after ore has been found, to one foot, the character of the sample and the depth of the hole being recorded at each sludging. Any change in the character of the rock should also be recorded, as this may aid in working out the structure. For structural purposes it is essential that the depth at which the oil-rock or clay bed is encountered and the relative elevations of the tops, of the holes above sea level or above some reference point be carefully observed and recorded. The first oil-rock seam encountered in Illinois is usually about ten feet above the clay bed, or base of the Galena dolomite.

In the search for ore deposits it is well to keep in mind the following points:[1]

First—In the present state of development it is always wise to select for prospecting, land which has in former years furnished considerable ore of lead, or of lead and zinc, above the level of ground water. Such districts can be recognized usually by the character of the surface, which has been more or less completely honeycombed with old workings. While it is not possible to say that deeper ore deposits will be found only, or always, below

[1] Grant, U. S. and Perdue, M. J., Millbrig sheet of the lead and zinc district of Northern Illinois Ill. State Geol. Survey, Bull. No. 8, p. 340, 1907.

Fig. 12. Map showing relation of Vinegar Hill mine to old workings and to topography. (Furnished by the Vinegar Hill Mining Co.)

these higher deposits of altered ores, it still is an almost universal rule that the deep deposits which are being worked today underlie deposits which were worked in years gone by.

Second—As the principal ores of the district, which are at present being mined, or which will be mined in the future, are the original metallic sulphides, these must be sought below the ground water level. It is therefore wise to select land in which there is considerable thickness—30 to 50 feet—of Galena limestone below the level of ground water.

Third—The best ore deposits are known to occur in synclinal basins, either at the bottom or along the sides of such basins. It is wise, then, to select an area which has this peculiar synclinal structure. If below any particular synclinal there is a considerable thickness of oil-rock, then the chances here are still better, for the oil-rock seems to have played an important part in the formation of these basins as well as an important part in the formation of the crevices and in the precipitation of the ores.

So far in the history of the district the prospecting has been confined almost entirely to those areas which have been large producers of lead ore, and these are still the most favorable places to prospect. However, the practice has been to drill about these old "diggings" in a haphazard manner until the zinc ore was encountered or the prospect deemed worthless. (See fig. 12.) Although it is true that many deposits have been found in this manner, it seems equally true that the percentage of blank holes has been unduly large and that some deposits have doubtless been missed. If we assume that the ores have been deposited from water solutions, a supposition which is in accord with all the theories of origin of the ores of this district, it follows that in seeking the continuation of a deposit, the ore should be sought in the direction in which the rock structures would cause the ore-bearing solutions to flow, i. e. in the direction of the dip of the beds. Surface exposures of the rocks may be lacking or the dip too small to be detected by the eye, yet the first two or three drill holes should give sufficient data to determine the general dip of the beds from which other holes could be "spotted." Areas in which the oil-rock is level are not favorable sites for the location of ore deposits.

The time during which prospecting may be directed by the old lead workings is fast coming to a close, for these areas have nearly all been prospected. It is therefore evident that, if mining is to continue, exploitation must be based upon the relation of the ore deposits to the topographic and structural features of the rocks. The manner in which the topography and structural features have influenced the ore deposits has been outlined on the previous pages. These relations are better understood if it be remembered that the topography and rock structures have determined the points of concentration and the direction of flow of the solutions from which the ores were deposited.

The first step towards the location of a suitable place to prospect would be to choose one near which the surface features had caused a concentration of surface waters, but this is not so easy as might be con-

cluded from this statement, for the ore deposits were formed a long time ago and it does not follow that the points where the drainage is now concentrated are points where it was concentrated during the time when the ore was being deposited. Yet it is due largely to the occurrence of ore along drainage courses that the hillsides and valleys are regarded as more favorable sites for prospecting than are the high lands.

In general the oil-rock basins are regarded as the more favorable areas to prospect, but ore deposits occur on the limbs and even on top of the oil rock ridges. The places at which prominent crevices appear at the surface mark points suitable for the accumulation of ore bodies, especially when they occur in the oil-rock basins. In general, crevices which strike parallel to the hill-side are regarded as more favorable than those which are normal to this direction, as they are in a position to catch the drainage from the sloping surface, although crevices running down the slope may carry ore in depth or even near the surface if the slope is low.

Sudden changes in the thickness and dip of the oil-rock beds also mark points where ore is likely to form and for this reason the ends of the oil-rock basins might be regarded somewhat more favorable than the sides. The determination of the structure of the underlying rock by surface indications is neither easy nor exact. It is true that the dip of the beds is often great enough to be determined by the eye so that the general direction of an oil-rock basin may thus be determined, but this observation must be supplemented by others such as the changes in level of the top or base of the flinty dolomite or of the *Receptaculites* zones before the basins can be accurately located. Such observations may not determine the exact position of the basin, but they are valuable, especially in the absence of other data, in determining the points at which the first drilling should be done. The records of these holes will then aid in the further determination of the structure.

Crevices may show at the surface, but they are often unexposed and can be inferred only from peculiar topographic features, such as depressions in the surface or small valleys which join larger ones at peculiar angles, and by the presence of springs.

The positions of the structural basins can be approximately determined within the areas for which oil-rock maps have been issued by the state geological surveys, otherwise their location must be determined largely by drilling as outlined above, although in any case all new records should be plotted in connection with those shown on the map to furnish a more accurate determination of the structure.

MINING

All the mines in the Illinois district are operated by means of shafts, although the Royal Princess mine is connected with the surface by an adit or tunnel. Although the mines may have a number of shafts, the ore is brought to the surface at only one place, usually at the outlet nearest the mill. One shaft is sunk about 10 feet deeper than the lowest part of the workings for the sake of drainage and the pumps are here installed. The ore is mined by the use of air, electric, and hand drills, but principally by the first. There is no question that the electric drills are the most efficient so far as the economy of power is concerned, but they are still in their trial stage regarding their adaptability to the conditions found in this district. After being broken at the face the ore is loaded by the trammers into large cans on trucks and pushed to the shaft where they are attached to the cable and hoisted to the surface to be dumped upon the grizzly over the ore bin.

Because of the large number of small companies operating in the field, the cost of mining has been rather high, but the last few years have seen a marked decrease in the number of small companies and an expansion in the larger ones, which has resulted in a marked improvement in both the methods and cost of mining. The conditions encountered in this field are not known to be duplicated elsewhere in the world, so that the methods used have been largely devised to suit the district. In general there is a tendency to increase the depth of the holes, the amount of powder used, and the size of the faces worked, which has resulted in some reduction in the cost of mining.

The installation of a central electric power plant at Galena by the Interstate Light and Power Company is a great aid to the mining industry. Power lines now run to all important mining centers in Illinois and Wisconsin so that electric power is available for most of the mines. It is not apparent that this power is cheaper than that locally developed by the use of coal, but it does have a number of important advantages, among which may be cited simplicity of plants, decrease in the cost of installation and maintenance, (provided a steam plant has not already been installed), a decrease in the time lost for repairs, and a large decrease in those troubles which are invariably associated with the purchase and transportation of coal.

MILLING

The milling practice in this northern district is similar to that of southwestern Missouri, although the mills of Illinois and Wisconsin are,

in general, of smaller capacity, each mill usually being able to treat from 50 to 150 tons of ore in 10 hours. The concentrating machinery generally consists of three seven-cell jigs known as the "rougher," "cleaner," and "sand" jigs respectively. The nature of the products from the various cells depends upon the arrangement of the mill as well as upon the relative amounts of galena, zinc blende, and iron sulphide in the ore. The waste products or tailings from the mills may be divided into two classes: (1) the coarse tailings, and (2) the fine tailings, sludge, or slimes as they are variously called. The first class contains usually between 0.7 and 1 per cent of zinc and the latter 6 per cent or more of this metal. It is thus seen, as is commonly the case in milling, that the main loss occurs in the slimes. Those who have attempted to treat the slimes on tables report that this is practical only with a high grade ore or slimes that contain considerable galena, as otherwise the product obtained is so fine and contains so much iron sulphide that it has no commercial value. At the present time the Northwestern mine is the only mine in northern Illinois that is using tables. The total recovery of the metallic sulphides by milling is low. But few mill tests have been made in the district but it is believed that the recovery by the various mills will range from 60 to 87 per cent, and average less than 75 per cent. This low recovery is due not necessarily to poor milling, but rather to the difficulty experienced in obtaining the zinc from the slimes in a commercial form in the presence of so much iron sulphide.

It is possible that efforts to increase the recovery of ore might better be exerted in the prevention of slimes rather than in their treatment after they have been formed. Sphalerite is brittle and slimes very readily. The common practice of using very tight rolls, sometimes without starwheels, and that of passing all of the ore through the breakers and rolls, materially aids in the formation of these "fines." A crushing system in which pieces of ore of the desired size could pass around or through the breakers and rolls without being subjected to further crushing, and thus be removed from the crushing department to the concentrating machines as soon as formed, should not only decrease the amount of fine material formed, but also decrease the amount of power used and increase the capacity of the breakers and rolls.

The water from the mine is usually sufficient for all mill purposes, but if not, it is ponded and used over and over, or the flow in the mine may often be increased by drilling through the oil-rock and clay beds. In some of the mines such holes are cased and the flow of water is regulated by means of a valve.

When iron sulphide is present in quantity, it causes considerable trouble in the milling of the ore, as it can be but partly separated from the blende by jigging. Roasting and magnetic separation has been tried at a number of places in Wisconsin and such a plant is now being operated by the Joplin Separating Company at Galena, Ill. This plant has a capacity of about 50 tons per 10 hours. Ore containing from 16 to 40 per cent zinc is partially roasted (without sizing) in a rotary tube and then passed through a Cleveland-Knowles separater, which gives a product containing about 58 per cent zinc. Much of this low grade ore is now being sold to the American Zinc Ore Separating Company at Platteville, Wis., which uses the Huff electrostatic machine to remove the iron from the concentrates. The processes employed in milling are shown in detail in fig. 13.
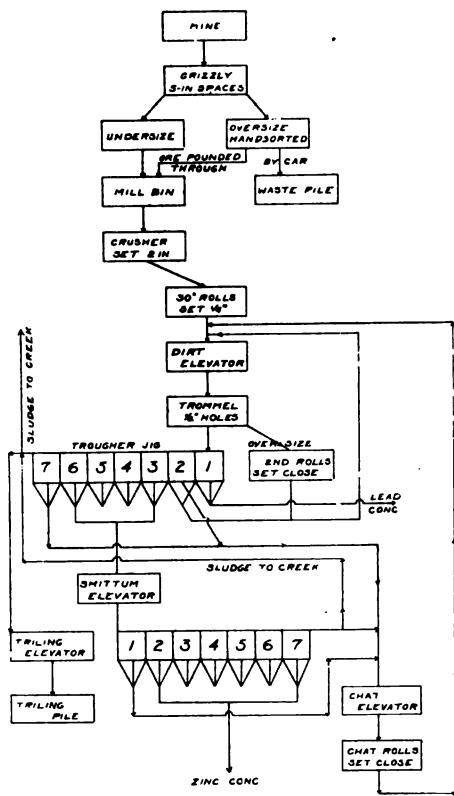
FIG. 13. Vinegar Hill mill flow sheet

COSTS

The general wages for an nine-hour shift in the northern Mississippi Valley district are as follows: machine men, $2.50 to $2.75; helpers ("backers"), $2.25; trammers, 6c to 7c a can, or 12c to 14c a ton; millmen, $3.50; all the other general help about the mine either above or below ground, $2.25.

The cost of mining varies greatly since it is dependent upon the size of the deposit, equipment, water to be handled, as well as certain personal factors. In general it ranges between $0.65 and $1.25, averaging a little less than $1.00 per ton of mill dirt, the cost per ton of concentrates depending upon the grade and character of the ore and the cost of milling. Most of the mining is done on leased ground so that there is

an additional expense in the way of royalties to be paid. The least, as well as the most common, royalty is 10 per cent of the gross output, although much larger royalties have been paid, and in some cases a cash bonus has been given.

The cost of milling, like that of mining, varies considerably with local conditions, but usually ranges between 18 and 40 cents, and averages about 27 cents per ton of ore treated.

The following is a comparison of the cost of mining and milling in the upper Mississippi Valley field with that of Joplin, Mo.:[2]

Generalized statement of the cost of producing spelter from a mine in Wisconsin yielding from its crude ore 10 per cent of concentrates, assaying 40 per cent zinc:

	Per ton Crude
Cost of mining, milling, and exploration	$1.40
Amortization of mining and milling plant	.33
Depreciation	.08
Magnetic separation of 40 per cent concentrates saving 90 per cent of the metal and producing 0.6 tons of 60 per cent concentrates $= \dfrac{\$2.00}{10} =$	.20
Freight to smelter $= \dfrac{\$1.50}{16.6} =$	.09
Smelting, saving 87½ per cent metal	.60
Amortization of smelting plant $= \dfrac{\$14.00}{166} =$	.08
Total cost	$2.78

$$\text{Yield} = \frac{1050}{16\tfrac{2}{3}} = 63 \text{ lbs. spelter per ton of ore.}$$

Cost per pound spelter, selling cost	4.41 cents
Dividend cost	3.76 cents

Generalized statement of the cost of producing spelter from Joplin ore, assuming 4 per cent of concentrates yielded per ton of crude ore milled, and neglecting royalties and other profits:

	Per ton Crude
Cost of mining and milling	$1.25
Amortization of mining and milling plant	.33
Depreciation	.08
Transportation to smelter	.06
Smelting, saving 87½ per cent	.40
Amortization of smelter at 10 per cent $= \dfrac{\$14.00}{250} =$	.06
General expense	.04
Total cost at smelter	$2.22

$$\text{Yield} = \frac{1050}{25} = 42 \text{ lbs. spelter per ton of ore.}$$

Cost per pound spelter	5.28

[2] Finlay, J. R., Cost of Mining, p. 322–323, 1909

It will be noted on comparing the above mining costs that the figures given for Wisconsin include the cost of exploration, whereas, those for Joplin apparently do not. The former is also charged with the cost of magnetic separation, a process which much of the ores does not undergo. On the other hand there is no charge for general expense estimated for the Wisconsin area. It is thus seen that the best mining and milling practice of the Wisconsin-Illinois-Iowa field compares very favorably with that of Joplin.

The living conditions are exceptionally good in the upper Mississippi Valley. The mines are so located that most of the men can have their homes in the small towns, and schools are always near at hand. Since it is situated in a farming district the quality of the food supplies is good and the cost of living fairly low.

FUTURE OF THE DISTRICT

The production of lead in commercial amounts in this field has continued for more than a century. However, the production of lead in quantity is now essentially a thing of the past, whereas that of zinc is probably near its height. The time through which a given deposit will last depends naturally upon the rate at which it is worked, and that of a district depends also upon the rate at which the deposits are discovered. Although at present prospecting is not being carried on so actively as in 1905 and 1906, it is done more thoroughly and systematically. Yet as the district grows older the deposits will become more difficult to locate and the production will consequently become smaller. It is believed by the author that ore will be mined in this district for *at least* the next 20 or 30 years, although not necessarily in the present quantity.

DESCRIPTION OF ACCOMPANYING MAPS

The accompanying maps (Pls. XIX, to XXII, inclusive), show five distinct types of features: (1) the surface elevations, including shape, size, and location of the hills, valleys, etc., are shown in brown (except in Pl. XIX); (2) the positions of all bodies of water or streams are shown in blue; (3) the works of man, known as culture, which include roads, houses, test pits, mines, boundaries, and many other features are indicated in black; (4) the elevation of the base of the Galena dolomite or main oil-rock bed at such points within the map as the data permit, is represented in green (except in Pls. XIX and XXII, Elizabeth); and (5) the various geologic formations which are exposed at the surface within the area mapped are indicated by various color and hatching schemes.

All elevations are referred to mean sea level. Series of level lines were run along the principal roads, and the heights of many points, especially road intersections, were thus accurately determined. These points are known as temporary bench marks and are commonly indicated by blazes on fence posts or telephone poles. Such bench marks are shown on the map by small black crosses followed by brown figures showing the elevations above sea level.

From the data obtained by leveling, supplemented by the use of the aneroid barometer, a series of contour lines were drawn. Such lines connect points of equal elevation above sea level and are drawn at regular vertical intervals. On this map the contour interval is ten feet, and the 50 and 100-foot lines are made heavier and numbered. By means of such contour lines the form of the surface of the land and the steepness of slopes, as well as th eelevation of the surface, is shown. This may become more evident by consulting a sketch (Pl. XVIII, *A*) of an ideal landscape, which represents the sea in the foreground and a river coming into the sea. The immediate river valley is flat-bottomed and is bounded on each side by steep slopes, above which the land rises quite gradually on the east, while on the west there is an almost precipitous rise to the top of a hill. The western side of this hill has a gentle slope. Pl. XVIII, *B* shows a model, viewed directly from above, of the same landscape, and on this model lines have been drawn connecting points of equal elevation. In Pl. XVIII, *C* the above lines are shown alone; this figure is a countour map (contour interval here is 20 feet) of the district shown in the ideal landscape (figure 31) and in the model (figure A of plate 23) of this landscape. Where slopes are steep, as on the west side of the river valley, the contour lines are close together; and where slopes are more gradual, as east of the river, the contour lines are farther apart, and are equally spaced if the slope is uniform.

To refer definitely to some point on the Millbrig map (Pl. XXII) take the junction of the roads near the southwest corner of sec. 33, T. 29 N., R. 1 E. Here there is a temporary bench mark, shown by a black cross, the elevation of the bench mark being 882.44 feet above sea level. The elevation of the ground at this point is something more than 880 feet but less than 890 feet. Going west along the road from this road junction, the ground is very level and it continues so with slight interruptions through the next section to the west. The highest point reached by the road in this latter section is near the center of the section where it goes somewhat above 890 feet. Returning again to the same road junction as above, and going north, it is seen that the road descends rather gradually for about one-half mile and then, in a distance of less than one-fourth mile, it descends over 100 feet into the valley of the stream which enters the Fever River just west of Millbrig.

The hard rock formations which outcrop in this district are four in number and the areas in which each formation actually comes to the surface, or immediately underlies the soil and decayed material of the surface, are shown by appropriate color symbols. The Niagara limestone, the most recent of the formations in this district, occupies only the higher portions of the area. The main part of the area, and especially the valley slopes, are occupied by the next underlying formations, the Maquoketa shale and the Galena dolomite. The lowest formation, the Platteville limestone, occurs only along the Galena or Fever River about 5 miles northeast of Galena near the southeast corner of the map. The boundaries between these formations are indicated by dotted black lines.

In addition to the distribution of these formations, two of the geological maps show the altitude and attitude of the base of the Galena dolomite by means of a series of structural contour lines (green in color.) The arrows on these green lines indicate the direction of the dip of the rocks.

Starting on the Millbrig sheet (Pl. XXII) at the Wisconsin State line in sec. 16, T. 29 N., R. 1 E., and going southward, a green line, marked 660, is soon crossed. This line indicates that the bottom of the Galena dolomite is here 660 feet above the sea level. The arrows show that the rocks are dipping toward the south. On continuing southward past the Unity Mine the
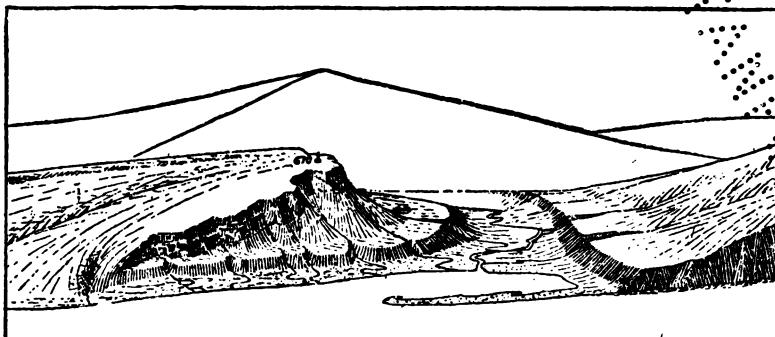
A. Sketch of ideal landscape.
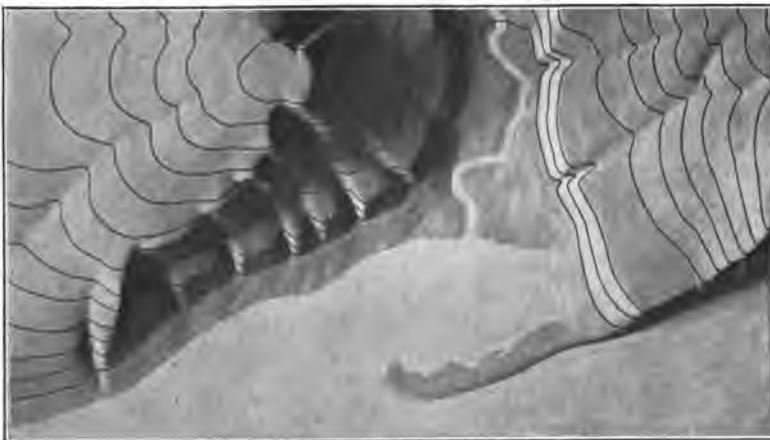
B. Model of ideal landscape.

C. Topographic map of ideal landscape.
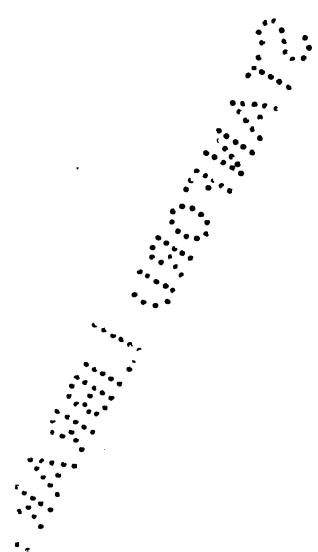
base of the Galena dolomite continues to descend until, near the center of sec. 21, T. 29 N., R. 1 E., it is something less than 630 feet above sea level and then descends again at the south edge of this section to less than 620 feet.

By means of the contour lines(shown in brown) and the structural contour lines (shown in green) it is possible to determine how far it will be necessary to drill at any particular point to strike the base of the Galena dolomite. For instance, in the bottom of the valley immediately north of the center of sec. 21, T. 29 N., R. 1 E., the contour lines show that the bed of the stream is approximately 745 feet above sea level, while the structural contour lines show that the base of the Galena dolomite is here a little less than 630 feet above sea level, or approximately 627 feet. The difference between these two figures (i. e., 745 and 627 feet), or 118 feet, will give the approximate depth to the base of the Galena dolomite at this particular point.[3]

In the Elizabeth area sufficient data in the way of drill records and exposures to warrant the mapping of the oil-rock are not available so that it has been omitted from this sheet. (Pl. XXII.) In the Galena area the data are still too meager to permit of an accurate determination of the structure of the oil-rock in some cases, so that the map (Pl. XX), should be used with care and understanding. The interpretation is given on the assumption that one who is familiar with the conditions may be better able to interpret the data than one who is not so familiar with them. The oil-rock basins and ridges are not so straight and simple as indicated on the map, but they show many minor irregularities which are often significant in locating ore deposits. It is therefore important to impress upon the reader the necessity of plotting all drill records with reference to the data given on the map, not only as a check to the map but also that the positions of these minor flexures or folds may be determined.

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